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Resource Targets for Advanced Underground Coal Extraction Systems

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U.S. Department of Energy
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ABSTRACT

This report identifies resource targets appropriate for federal sponsorship of research and development of advanced underground coal mining systems. The geological data used in the analysis came from A Study of the United States Coal Resources by John Ferm and Paul Muthig of the University of Kentucky, Lexington. In contrast to previous research, which focused on a particular resource type, this study made a comprehensive examination of both conventional and unconventional coals, with particular attention to exceptionally thin and thick seams, steeply dipping beds, and multiple seam geometry.

The major thrust of the targeting analysis was forecasting which coals would be of clear commercial significance at the beginning of the 21st century under three widely different scenarios for coal demand. The primary measure of commercial importance was an estimate of the aggregate dollar savings realized by consumers if advanced technology were available to mine coal at prices at or below the price projected for conventional technology in the year 2000. Both deterministic and probabilistic savings estimates were prepared for each demand scenario.

The results indicate that the resource of primary importance is flat-lying bituminous coal of moderate thickness, under moderate cover, and located within the lower 48 states. Resources of secondary importance are the flat-lying multiple seams and thin seams (especially those in Appalachia). The rather substantial deposits of bituminous coal in North Alaska and the deeply buried lignites of the Gulf Coast present transportation and ground control problems which appear to postpone their commercial importance well beyond 2000. Steeply dipping coals, abandoned pillars, and exceptionally thick western coals may be important in some regions or sub-regions, but the limited tonnage available places them in a position of tertiary importance.

FOREWORD

This report identifies resource targets appropriate for research and development of advanced underground coal mining systems. The study reported here is one of a series of documents produced by a program to define, develop, and demonstrate coal mining systems with substantially improved production cost and safety performance, while complying with regulatory intent in the areas of miner health, environmental impact, and coal conservation. Earlier reports established systems performance goals and conceptual design requirements. A companion document by Ferm and Muthig (1982) describes the results of a geological study of generic resource types, including estimates of the tonnages associated with commonly occurring sets of mining conditions.

The program is funded by the Division of Coal Mining, the United States Department of Energy via an interagency agreement with the National Aeronautics and Space Administration (DOE Contract No. 76ET12548; NASA Task Order RD152, Amendment 90). William B. Schmidt was the project officer for the Department of Energy.

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EXECUTIVE SUMMARY

This report identifies resource targets appropriate for research and development of advanced underground coal mining systems. The study reported here was performed for the Division of Coal Mining, the U.S. Department of Energy in an attempt to assist that agency in establishing research priorities within a program to define, develop, and demonstrate advanced underground coal mining systems. The definition of an advanced system is discussed at length in Goldsmith and Lavin (1980), which provides broad performance goals, and Gangal and Lavin (1981), which provides conceptual design requirements for a common resource type. For purposes of this document, it suffices to say that an advanced underground mining system must 1) yield a very attractive return on incremental investment, and 2) substantially reduce deaths and disability injuries, while 3) simultaneously complying with regulatory intent in the areas of miner health, environmental impact, and the protection of unmined coal.

Study results are documented in two volumes. The first volume, entitled A Study of the United States Coal Resources (Ferm and Muthig, 1981), is primarily concerned with the identification of geologically significant coal deposits, described in terms of broad categories of mining conditions. Section II of this report summarizes the findings of that study. This report comprises the second volume. It develops a rationale for the recommended targets, based largely on the projected commercial significance of these coals.

The nature of this study required an emphasis on order of magnitude results and an explicit treatment of uncertainty. The geological study undertook to differentiate between major resource types in terms of the order of magnitude of the tonnage present. As a result, it was necessary to neglect totally a number of minor deposits and to measure the tonnage in the larger basins to a precision of ± billion tons. A higher level of precision was simply not required to set R&D priorities. Similarly, in the evaluation of commercial significance (reported in this volume) the primary objective was to identify the conditions for which one resource type clearly dominated another, with the intent of producing a well-defined and stable ranking of coals.

Previous studies which examine the national resources in a comprehensive fashion were primarily concerned with "conventional coals"--flat-lying seams of moderate thickness, under moderate cover. Individual studies have been made of particular resource types (e.g., steeply dipping coals, thick seams, multiple seams, and thin seams). However, these studies used radically different methods, some of which are difficult to assess from the information available in published reports. Moreover, the data utilized in this previous work is of a quite uneven quality, some estimates being used primarily on outcrop measurements, other estimates using logs and cores extensively. Finally, the degree of precision of previous studies is practically impossible to ascertain, there being little or no meaningful attempt to quantify the accuracy of measurement.

Considerable potentially relevant work on a coal supply has been done in the area of long-term energy price forecasting. These efforts typically use large computer models of the national energy sector. Examination of those models reveals a wealth of information relevant to the future costs of mining coals from the demonstrated reserve base (flat-lying seams of moderate thickness, under moderate cover) but little information on unconventional resource types (very thick coals, steeply dipping coals, etc.)

Thus, to satisfy the peculiar needs of this project to develop advanced mining systems, it was clear that a new study was needed. A primary objective of this study was the characterization of coal resources (not just reserves) without imposing any limits on seam thickness, dip, overburden, environmental suitability to mining, etc. Once a complete description of the resources were in hand, this information was combined with available data on production and transportation costs to determine which resource types could have a large enough impact on national energy supply to warrant the expenditure of federal funds on mining R&D.

GEOLOGICALLY SIGNIFICANT COALS

The primary objective of the geological portion of the study was to estimate the tonnages of coal and lignite found in the national resources, and subsequently partition these tonnages into a set of generic resource types, each of which is characterized by a well-defined set of mining conditions or constraints. The basic mining constraints include the thickness of a mineable seam, its structural attitude or departure from the horizontal, the amount of overburden covering a seam, interburden or distance between adjacent seams, discontinuity of a seam produced by faulting or igneous intrusion, and the quality of the coal or lignite. Added to this list are the geographic location of the coal provinces in which the resource occurs, and the average size of a mineable block (not examined in this study).

The results of the geological study offer clear guidance for the development of advanced mining systems to enhance the exploitation of U.S. coal and lignite resources. Firstly, there is strong evidence that the total resources have been underestimated by at least 100%, and that a substantial body of the coal and lignite occur at depths greater than 2000 ft. A large fraction of these deposits are found below depths where coal is currently mined in the United States, with the deep coals occurring mainly in the Gulf Coast and North Alaska, and to a lesser extent in the Rocky Mountain Province. The poorly consolidated character of the rocks in the Gulf Coast and the extreme depths of much of the North Alaskan coals suggest that utilization of these deeply buried resources is best accomplished by unconventional techniques, probably involving in situ comminution or conversion.

Secondly, the data indicate that 1.2 trillion tons of resources lie within 500 ft of the surface, and thus, within the ordinary range of surface mining. These resources are roughly equally distributed across the coal provinces of the contiguous United States, and hence, comprise a readily available short-term resource. Extraction technology in this area is similar to that utilized in other excavation enterpises and has benefitted greatly from the transfer of technology.

Thirdly, these data indicate that substantial amounts of bituminous and subbituminous coal occur at depths suitable for underground mining (less than 2000 ft), with shallow inclination, and absence of faults and igneous intrusions--all of which simplify underground operations. These bodies of coal occur mainly in the Rocky Mountain, Interior, and Appalachian Provinces where an infrastructure already exists for underground extraction. Within these areas, efforts toward the enhancement of extraction technology should be directed to seams in the range of 15 ft - 42 in. since only a small proportion of the resources occur in seams thicker than 15 ft. It appears that technological advancement in mining coals 15 ft - 42 in. thick would be best directed toward improving the capability of existing systems for the extraction of isolated (non-interfering) seams. However, a potential for major technological innovation exists in the recovery of multiple seam deposits and coals thinner than 42 in. The relatively small indicated tonnage of seams which can be mined in isolation has strong implications for resource conservation. As mining proceeds in Appalachia and the older coal fields of other provinces, depletion of the resource will occur at a rate much higher than may be apparent because of inattention to the mutual interference of closely adjacent coal beds. Accordingly, multiple seams are regarded as a resource of long-term national importance and of short-term importance in those coal fields where mining has been intensive.

Finally, this study has shown that only a relatively small proportion of the U.S. resources occur in steeply dipping, faulted, or intruded bodies. Consequently, although some of this coal is of good to excellent quality, the technical problems associated with it, relative to the total volume available, place it in a position of secondary importance compared with coals that can be more easily extracted.

COMMERCIALLY SIGNIFICANT RESOURCES

The second task in the formulation of resource targets required an analysis of the commercial significance of the resource types previously identified in the geological study (see Table ES-1).

The primary criterion for assessing the commercial significance of a resource was a projection of aggregate national savings in annual energy expense circa the year 2000, as a result of the lowering of the delivered price by a specified amount. Secondary targeting considerations were:

- To provide an advanced coal extraction system that would be financially attractive to the small miner.
- Minimize the required social and/or economic disruptions.
- Select resources so that a maximum amount of strip-mined coal production is replaced.

The computation of aggregate national savings was done in both a deterministic and probabilistic fashion. In the deterministic format, savings were calculated from a presumed shift in regional supply curves as a result of introducing new mining technology which yields a lower mine-mouth price. Probabilistic savings were then estimated by combining the deterministic cost savings with the likelihood of achieving the level of price reduction on which the savings were predicated.

Results were determined for three distinct demand scenarios, assuming 46, 34.5, and 23 quads of demand for coal, circa 2000. These three scenarios were selected after a review of 35 distinct forecasts of demand made under differing assumptions about government policies to encourage both energy and resource conservation.

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Table ES-1. Summary of Resource Types for the United States*

Resource Type	Tonnage (Billions)	Percent
Flat-lying coal above 2000 ft:		
Seams 15 ft - 28 in.		
Multiple seams	2,500	21.4
Isolated seams with ≥ 75% coal	1,300	11.1
Isolated seams with < 75% coal	50	0.4
Abandoned pillars	30	0.3
Seams 28 - 14 in.	910	7.8
Seams thicker than 15 ft	310	2.6
SUBTOTALS	5,100	43.6
Flat-lying coal below 2000 ft:	6,500	55.5
Coal dipping more than 15°, faulted or intruded	100	0.9
TOTALS	11,700	100.0

*Source: Ferm and Muthig (1982).

Both the deterministic and probabilistic analysis of savings indicate the clear dominance of so-called conventional coals (flat-lying seams of moderate thickness, under moderate cover, mined one at a time) over thick seams, except for thin shaft coals which may be as attractive as thick seams under either a very high or very low demand scenario. As indicated in the initial screening of resource types, these conventional coals are inextricably confounded with multiple seams, with the latter currently exhibiting a somewhat higher mining cost. The abundance of multiple seams (see Section II) together with their higher mining cost implies a level of savings of the same order of magnitude but numerically less than the more attractive conventional coals. Within the category of conventional coals, seams which are accessible via drift entry are the more attractive, with medium thick seams (15 ft - 42 in.) having top ranking in all cases analyzed. As indicated in Section VIII, these findings are rather insensitive, both to changes in the parameters of the probability density function used in the calculation of expected savings and to the assumed demand scenarios.

An examination of the secondary targeting criteria reveals that selection of drift entry coals would be attractive to the small operator; nomination of thick coals would favor the Rocky Mountain region and might possibly lead to displacement of some surface mining production; and the choice of multiple seams would, in the short-term, tend to favor those regions where depletion has been significant (Appalachia and the Interior Basin), but would, in the longer term, benefit all regions.

The diverse nature of the resource targets leads to another, higher level, targeting consideration. It is very likely that the optimal expenditure of funds on research and development requires funding of more than one project. The basic reason is that the level of "success" generated by a research and development effort is unknown and uncertain. One way to reduce the risk of failure is to allocate research and development money to a carefully chosen portfolio of projects. Although alternative strategies to manage risk are available, a common strategy is to choose projects with different levels of uncertainty. If that strategy is favored, the coals should be categorized by the likely risk of developing commercially attractive mining systems.

Below is a classification of the various resource types by degree of risk, with Category I coals (flat-lying coals of moderate thickness, under moderate cover) exhibiting the least risk (highest likelihood of a substantial payoff), and Category II and II coals, increasingly higher risk:

CATEGORY I	CATEGORY II	CATEGORY III
- Conventional Coals: Flat-lying seams of moderate thickness, under moderate cover	- Thick Seams - Multiple Seams - Thin Coals - Rock/Coal - Lignites - Deep Coals	- Alaskan Coals - Abandoned Pillars - Steep Coals

In consequence, the targeting recommendations can be summarized as follows:

(1) Some conventional coals should be chosen. These coals have the greatest economic potential and generally satisfy all criteria.

(2) Some Category II coals could be chosen. The coal to choose depends on factors not considered in this analysis. Almost every one of these coals could have important impacts on a given region, although the thin coals and the deep coals also have national constituents.

(3) If some funds are available for research on more speculative projects, the Category III coals would come into consideration. Again, precisely which coal to choose depends on other factors.

SECTION I

STUDY BACKGROUND AND OBJECTIVES

This study was performed for the Division of Coal Mining, the U.S. Department of Energy in an attempt to assist that agency in establishing research priorities within a program to develop advanced underground coal mining systems. The definition of an advanced system is discussed at length by Goldsmith and Lavin (1980), which provides broad performance goals, and Gangal and Lavin (1981), which provides conceptual design requirements for a common resource type. For purposes of this document, it suffices to say that an advanced underground mining system must 1) yield a very attractive return on incremental investment and 2) substantially reduce deaths and disability injuries, while 3) simultaneously complying with regulatory intent in the area of miner health, environmental impact, and the protection of unmined coal.

A. OBJECTIVES AND GROUND RULES

Geologic conditions which surround a coal deposit are primary considerations in the design of a mining system as well as the planning of an individual mining operation. Even a cursory examination of the United States coal resources reveals a great variety of conditions, including deep coals, very thick coals, very thin coals, steeply dipping coals, multiple seams, coals which contain a lot of rock, etc. Since mining conditions are so important to the design of a new mining system, a rational approach to setting research and development (R&D) priorities must begin with a set of resource targets. It is the purpose of this study to formulate those resource targets at a level of detail which will permit systematic development of design requirements for each resource selected.

Study results are documented in two volumes. The first volume, entitled A Study of the United States Coal Resources (Ferm and Muthig, 1982), is primarily concerned with the identification of geologically significant coal deposits, described in terms of broad categories of mining conditions. Section II of this report summarizes the findings of that study. This report comprises the second volume. It develops a rationale for the recommended targets, based largely on the projected commercial significance of these coals.

The nature of this study requires an emphasis on order of magnitude results and an explicit treatment of uncertainty. The geological study undertook to differentiate between major resource types in terms of the order of magnitude of the tonnage present. As a result, it was necessary to neglect totally a number of minor deposits and to measure the tonnage in the larger basins to a precision of a billion tons. A higher level of precision was simply not required to set R&D priorities. Similarly, in the evaluation of commercial significance (reported in this volume) the primary objective was to identify the conditions for which one resource type clearly dominated another, with the intent of producing a well-defined and stable ranking of coals. Thus, a particular measure of economic importance--such as aggregate savings in energy costs--had no intrinsic economic significance beyond its use to sharpen the apparent differences in the commercial attractiveness of various types of deposits.

The necessity to deal with uncertainty entered into both the geological and economic aspects of the study. In the case of tonnage estimates, the precision of the estimates was described in terms of statistically based confidence limits rather than a breakdown of tonnage into the traditional categories of "measured, indicated, inferred," etc. Such a quantitative approach, although unusual in the preparation of coal tonnage estimates, seemed well suited to a methodological approach which was based upon the blocking of fields and basins into geologically homogeneous units.

In the assessment of commercial significance, two types of uncertainty were considered: 1) undertainty in the future demand for coal, and 2) uncertainty about the mine-mouth price likely to be achieved by the (as yet undefined) advanced technology. Demand uncertainty was handled via the use of three widely different demand scenarios which were constructed to span the spectrum of previously published forecasts. Price uncertainty was handled by a classic probabilistic analysis of the likelihood of realizing a specified reduction in minimum acceptable selling price, f.o.b. mine.

B. REVIEW OF PREVIOUS WORK

In the initial attempts to answer the questions set as objectives for this study, we examined a number of previous studies in the hope that someone else had either resolved the issues or else gathered pertinent data. Such was not the case.

Previous studies which examine the national resources in a comprehensive fashion were primarily concerned with "conventional coals"--flat-lying seams of moderate thickness, under moderate cover (e.g., Averitt, 1975). Individual studies have been made of particular resource types (Skelly and Loy, 1980, for steeply dipping coals; Bise, 1978, for thick seams; Engineers International, 1981, for multiple seams; Pimental et al, 1979, for thin seams). However, these studies used radically different methods, some of which are difficult to assess from the information available in published report. Moreover, the data utilized in this previous work is of a quite uneven quality, some estimates being used primarily on outcrop measurements, other estimates using logs and cores extensively. Finally, the degree of precision of previous studies is practically impossible to ascertain, there being little or no meaningful attempt to quantify the accuracy of measurement.

Considerable potentially relevant work on a coal supply has been done in the area of long-term energy price forecasting. These efforts began with the construction of a large computer model of the national energy sector, called the Project Independence Energy System (PIES) which subsequently evolved into a model called the Mid-Term Energy Forecasting System (MEFS), currently used by DOE for policy analysis. As part of this model development effort, various detailed submodels have been constructed for the coal supply sector. One of these models, developed originally for the Environmental Protection Agency, was used to project regional target prices suitable for the conceptual design of advanced mining systems (see Terasawa and Whipple, 1980).

Examination of those models reveals a wealth of information relevant to the future costs of mining coals from the demonstrated reserve base (flat-lying seams of moderate thickness, under moderate cover) but little information on unconventional resource types (very thick coals, steeply dipping coals, etc.).

Easy to mine coal is in such abundance that more challenging resource types simply did not have to be considered in making 20 year price projections--forecasts which are probably at the limits of credibility in any event.

Thus, to satisfy the peculiar needs of this project to develop advanced mining systems, it was clear that a new study was needed. A primary objective of this study was the characterization of coal resources (not just reserves) without imposing any limits on seam thickness, dip, overburden, environmental suitability to mining, etc. Once a complete description of the resources were in hand, this information would be combined with available data on production and transportation costs to determine which resource types could have a large enough impact on national energy supply to warrant the expenditure of federal funds on mining R&D.

As indicated above, the results of the geological study are reported separately by Ferm and Muthig (1982), but summarized in Section II for the convenience of the reader. Section III presents an overview of the assessment of commercial significance, a key consideration in the targeting methodology. Explicit targeting criteria are developed in Section IV, and demand scenarios which establish the macro-economic context of the study are developed in Section V. The assessment of commercial significance begins in Section VI with an initial screening of the comprehensive set of resource types, followed by detailed analysis of selected resource types in Section VII, and a treatment of mining cost uncertainty in Section VIII. Resource targets, together with the rationale for their selection, are presented in Section IX.

SECTION II

GEOLOGICALLY SIGNIFICANT RESOURCES*

A. SUMMARY OF RESOURCE ESTIMATES

The primary objective of this study is the estimation of U.S. coal and lignite resources with a view to guiding future research on advanced mining systems. As practiced today, coal mining is a product of constraints imposed by both the material itself and mining methods established through long practice. Although new methods may be devised, the basic constraints remain, namely, the thickness of a mineable seam, its structural attitude or departure from the horizontal, the amount of overburden covering a seam, interburden or distance between adjacent seams, discontinuity of a seam produced by faulting or igneous intrusion, and the quality of the coal or lignite. Added to this list are the geographic location of the coal provinces in which the resource occurs, and the average size of a mineable block (not examined in this study).

A summary of the estimated tonnage for each of the major U.S. coal provinces is given in the last two columns of Table 2-1, which reports an aggregate resource of about 11.7 trillion tons. As Table 2-1 indicates, the total resources are not equally distributed. The bulk of the tonnage resides in the Gulf Coastal Plain and North Alaska, each having about 30% of the total; approximately 20% occurs in the Rocky Mountain Province; and the Appalachian Plateau, Interior, and High Plains Provinces each account for 5 - 7% of the aggregate tonnage. If it is assumed that most of the resources in the Gulf Coast and High Plains Provinces are lignite, it is clear that lignite comprises about 40% of the aggregate U.S. Resources, the remaining 60% being predominantly subbituminous and high-volatile bituminous coal. Coals with a rank above high-volatile bituminous do not comprise more than about 1% of the total resources.

Table 2-1 also compares the detailed estimates of this report with those published in the <u>1980 Keystone Coal Industry Manual</u>. The most conspicuous feature of these data is that the 11.7 trillion ton estimate produced by this study is about three times greater than the aggregate of the Keystone estimates, with the major differences arising from the addition of over 3.5 trillion tons each for the Gulf Coast and North Alaska Provinces. However, from the point of view of both quantity and quality of the basic data, the estimates for North Alaska and the Gulf Coast are not nearly so well controlled as those for the other provinces. Nonetheless, the results of this study do suggest that the importance of Alaska and the Gulf Coast Provinces has been seriously underestimated.

This study has shown that the attributes of structural attitude and discontinuity due to faulting or igneous intrusion probably do not constitute major constraints in the total body of U.S. coal resources. Preliminary tonnage estimates for all coal provinces indicate that only about 3% of the total U.S. resources occur in fields where a large fraction of the seams are inclined at angles greater than 15°, or rendered discontinuous by faulting

*The material in Section II has been adapted from Section 6.0 of Ferm and Muthig (1982).

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Table 2-1. Resource Estimates in U.S. Coal Provinces in Which Steep Dips, Faults, and Igneous Intrusions are not Major Characteristics

(Tonnage is Expressed in Billions)*

Province	1980 Keystone Estimates		University of Kentucky Estimate	
	Tonnage	Percent	Tonnage	Percent
Appalachian Plateau	400	11	810	7
Interior Basins	540	14	740	6
Gulf Coast	40	1	3,790	33
High Plains	660	17	610	5
Rocky Mountains	1,830	49	2,190	19
North Alaska	290	8	3,510	30
TOTAL	3,760	100	11,650	100

*Tonnages may not add to totals shown elsewhere due to round-off.

or igneous intrusion. Moreover, within those basins or fields in which such features are relatively less abundant, it is estimated that tonnages affected in this way probably do not exceed 1% of the total (see Table 2-2). Hence, in evaluating total coal and lignite resources, the major constraints are depth of cover, seam thickness, and the geographic area of occurrence.

1. Depth of Cover

In order to describe current U.S. practice and give a feeling for the extreme ground pressures surrounding the very deepest coals, the categories used to describe depth of cover were 0 - 500 ft, 500 - 2000 ft, 2000 - 4000 ft, and greater than 4000 ft. Extraction by surface methods at depths of up to 500 ft is envisioned, and subsurface mining at depths up to 2000 ft is currently practiced. Mining at depths of 2000 - 4000 ft is possible, but only with increasing difficulty and expense. Resources at depths greater than 4000 ft are probably not extractable as solids, but are candidates for in situ combustion or similar processes. Viewed this way, slightly over 40% of the U.S. resources are extractable via currently available or readily foreseeable mining methods, and nearly 60% occur at depths where mining is difficult or impossible (see Table 2-3). Of the 40% of the resource under less than 2000 ft of cover, about one-quarter is available for surface mining at depths down to 500 ft, and the remainder is within the range of underground mining.

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Table 2-2. Summary of Original and Remaining Resources by Seam Thickness, Depth of Cover, and Degree of Disturbance

(All Tonnage Expressed in Billions)*

	Dipping less than 15°, and no Faults or Intrusions										Dip >15° Faulted, and/or Intruded	Totals
	0 - 2000 ft											
	50 ft	50 - 15 ft	15 ft - 42 in.	42 - 28 in.	28 - 14 in.	0 - 2000 ft	0 - 500 ft	500 - 2000 ft	2000 - 4000 ft	4000 ft		
Original Tonnage	56	260	2862	911	959	5048	1226	3822	4081	2469	124	11,722
Tonnage Mined/Lost	0	1	51	19	3	74	37	37	0	0	0	74
Remaining Tonnage	56	259	2811	892	956	4974	1189	3785	4081	2469	124	11,648
Percent	0.5	2	24	8	8	43	10	33	35	21	1	100

*Figures may not add to indicated totals due to round-off.

Table 2-3. Remaining Resources in Beds not Faulted or Intruded and Dipping Less Than 15 Degrees, by Depth of Cover and Coal Province

(Tonnage is Expressed in Billions)*

Province	0 - 500 ft		500 - 2000 ft		2000 - 4000 ft		4000 ft		TOTAL	
	Tonnage	Percent	Tonnage	Percent	Tonnage	Percent	Tonnage	Percent	Tonnage	Percent
Appalachian Plateau	236	2.1	545	4.7	28	0.2	0	0.0	809	7.0
Interior Basin	288	2.5	408	3.5	31	0.3	0	0.0	727	6.3
Gulf Coast	402	3.5	1,519	13.2	1,409	12.2	456	3.9	3,786	32.8
High Plains	59	0.5	534	4.7	14	0.1	0	0.0	607	5.3
Rocky Mountains	190	1.7	428	3.7	63[illegible]	5.5	832	7.2	2,080	18.1
North Alaska	14	0.1	352	3.1	1,969	17.1	1,180	10.2	3,515	30.5
TOTALS	1,189	10.4	3,786	32.9	4,081	35.4	2,468	21.3	11,524	100.0

*Tonnages may not add up to totals shown due to round-off.

However, because of the rock materials in which these resources occur, easily mineable coals total somewhat less than 40% of the aggregate. In particular, the 2 trillion tons at depths of 500 - 2000 ft in the Gulf Coast and High Plains Provinces are probably not available for underground mining because of the unconsolidated character of the materials which enclose these lignite bodies; i.e., these resources and could be placed in the category of "extractable only with great difficulty." Consequently, readily mineable U.S. resources are probably about one-quarter of the total, with the remaining three-quarters recoverable only by unconventional methods. Therefore, one of the major directions in R and D on resource exploitation should be development of technology for exploiting the resources for which ground control is the paramount technological constraint--deeply buried bituminous and subbituminous coals, and deep mineable lignites surrounded by rock of very low competence.

Of the readily extractable 3 trillion tons, about one-third can be considered available for surface mining methods, the remainder being suitable for underground mining. Of the coals that can be surface mined, the bulk appear to be located mainly in the Gulf Coast Province and to a lesser degree in the Appalachian Plateau, the Interior Basin, and the Rocky Mountain Province. However, until more definitive data are available for the Gulf Coast, all of these four provinces should be regarded as roughly equal in resources available for surface mining, leading to a conservative estimate of surface mineable resources of about 250 billion tons. Any consideration given to enhancement of surface mining techniques in these provinces should recognize the major differences among them. Rocks enclosing the lignites of the Gulf Coast are very poorly consolidated relative to the other provinces, and can be readily excavated. However, for the same reasons, highwall and spoil pile stability could present serious problems, further aggravated by the proximity of large quantities of subsurface water. On the other hand, the rather level character of the Gulf Coastal Plain topography, combined with the low structural inclination of the seams, enhance the possibilities of surface mining, as do similar conditions in the Interior Province. Surface mining in the more rugged terrain of the Appalachian Plateau or Rocky Mountain Provinces could be aided by development of improved methods for handling highly variable thicknesses of overburden occurring in close geographic proximity.

Tonnages readily available for underground mining at depths of 500 - 2000 ft amount to about 10 - 15% of the total U.S. resources if the lignites in the poorly consolidated rocks of the Gulf Coastal Plain and High Plains are excluded (Table 2-3). These readily mineable underground resources, together with the roughly 250 billion tons conservatively available for surface mining, comprise the easily extractable coal resources of the United States. Virtually all of this coal is of at least subbituminous rank, and some includes medium- and low-volatile bituminous deposits. These resources are located in the Rocky Mountain, Interior, and Appalachian Plateau Provinces, with each province containing roughly the same magnitude of resource potential. Since mining conditions and methods, as currently practiced, are about the same in each of these three provinces, advanced extraction techniques developed in one area would probably be applicable to another.

2. Seam Thickness

Seam thickness, as a mining constraint, is of importance primarily in underground mining. In surface mining the governing factor is the ratio of total coal to the volume of the rock to be removed. Thus, unless only a single seam is to be mined, the thickness of any one seam is of little importance. The thickness categories used in this study reflect the approximate relationship of seam thickness to underground mining methods currently being employed. Some European collieries practice multiple slice longwalling of thick coals, and recent reports indicate the availability of powered shields which can support a 20 ft roof. However, there is, at present, no accepted technique for mining North American seams much in excess of 15 ft, and as a rule, a substantial section of the coal in thick American seams is left on the roof and floor. The probable range of seam thickness for current underground mining is 15 ft - 42 in. Fifteen feet slightly exceeds an optimum of 6 - 9 ft for most commercially available equipment, and 42 in. represents a tolerable lower limit for commonly used mining machines. Seams less than 42 in. high can be categorized as difficult to mine, and seams thinner than 28 in. are currently mined only under special circumstances.

Table 2-4 shows the distribution of U.S. resources by thickness category for those seams which are gently inclined, not faulted or intruded, and lying under less than 2000 ft of overburden--i.e., resources that are most suitable for underground mining. Table 2-4 indicates that in this category of resources, seams in excess of 15 ft represent a very small proportion of the total, with about half of these occurring in either the Gulf Coast or High Plains Provinces, where weakness of the surrounding strata would very likely preclude the possibility of significant underground extraction. Moreover, the attractiveness of thick seams as an R and D target diminishes when one recognizes that it is at least theoretically possible to mine the bulk of the resource over 15 ft with a two-pass, top slicing longwall, leaving at most a few feet of coal between slices (a state-of-the-art technique in Europe). Hence, primary interest must be focused on seams with thicknesses of less than 15 ft. About half of these resources are in seams 15 ft - 42 in. thick, and the remainder in this seams of 42 - 14 in. However, over half of the tonnage in the 15 ft - 42 in. category is located in the Gulf Coast and High Plains Provinces, and is probably not suitable for extraction by underground methods. In addition, thin seam resources in the High Plains, Rocky Mountain, and Gulf Coast Provinces have probably been underestimated because beds of this thickness are generally not regarded as mineable in those regions, thus discouraging the exploration of these coals as well as the careful reporting of thin coals in recorded logs. Hence, in order to evaluate seam thickness data in the context of underground mining, data from the Gulf Coast and High Plains should be excluded, and thin seam tonnages for the Rocky Mountain Province should be regarded as underestimated.

Accordingly, data from Table 2-4 are recast into Table 2-5 which excludes seams thicker than 15 ft as well as all Gulf Coast and High Plains coal. Table 2-5 shows that, overall, about half of the "adjusted" underground tonnage occurs in seams from 15 ft - 42 in. thick, and half in seams of 42 - 14 in. If the Rocky Mountain and North Alaskan tonnages have been underestimated, then it may be expected that a substantial body of readily available underground tonnage occurs in the thin seam category. At first glance, these data appear to have clear implications for the development of advanced underground mining systems. Thicker coals are widely regarded as easier and cheaper to mine; moreover, any thin coal must generally compete with closely adjacent thicker coals, under the assumption that nearby thick coals have not been seriously depleted. This logic implies that R&D efforts should be channeled into systems suitable for mining seams 15 ft - 42 in. thick, and indeed, most

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Table 2-4. Remaining Resources in Beds not Faulted or Intruded, Dipping Less Than 15 Degrees and Lying Under Less Than 2000 Feet of Cover, by Seam Thickness and Coal Province

(Tonnage is Expressed in Billions)*

Province	50 ft Tonnage	50 ft Percent	50 - 15 ft Tonnage	50 - 15 ft Percent	15 ft - 42 in. Tonnage	15 ft - 42 in. Percent	42 - 28 in. Tonnage	42 - 28 in. Percent	28 - 14 in. Tonnage	28 - 14 in. Percent	TOTAL Tonnage	TOTAL Percent
Appalachian Plateau	0	0.0	0	0.0	321	5.5	207	4.2	253	5.0	781	15.7
Interior Basins	0	0.0	0	0.0	228	4.7	137	2.7	331	6.6	695	14.0
Gulf Coast	14	0.3	32	0.6	1306	26.2	376	7.6	193	3.9	1921	38.6
High Plains	0	0.0	63	1.3	404	8.1	63	1.2	63	1.3	593	11.9
Rocky Mountains	19	0.4	81	1.6	375	7.5	72	1.5	71	1.4	618	12.4
North Alaska	23	0.5	83	1.7	177	3.5	37	0.8	45	0.9	366	7.4
TOTALS	56	1.2	259	5.2	2811	56.5	892	18.0	956	19.1	4974	100.0

*Tonnages may not add up to totals shown due to round-off.

Table 2-5. Remaining Resources in Beds 15 ft to 14 in. Thick, Which Are Not Faulted or Intruded, and Lie Under Less than 2000 ft of Cover, in All Provinces Except the Gulf Coast and High Plains

(Tonnage is Expressed in Billions)*

Province	15 ft - 42 in.		42 - 28 in.		28 - 14 in.		TOTAL	
	Tonnage	Percent	Tonnage	Percent	Tonnage	Percent	Tonnage	Percent
Appalachian Plateau	321	14.2	207	9.2	253	11.2	781	34.6
Interior Basins	228	10.1	137	6.1	331	14.6	696	30.8
Rocky Mountain	375	16.6	72	3.2	71	3.2	518	23.0
North Alaska	177	7.8	37	1.7	45	2.1	259	11.6
TOTALS	1101	48.7	453	20.2	700	31.1	2254	100.0

*Tonnages may not add to indicated totals due to round-off.

research in underground mining is concentrated in this range of seam thickness. On the other hand, methods of mining seams thinner than 42 in. appear to be adaptations of procedures used in the thicker seams, and the smaller interest in commercial development of thin seams would appear to reflect, at least in part, a lack of suitable technology for rapid and efficient extraction of coal from low seams. This, coupled with the fact that a large proportion of readily available underground resources occurs in thin seams, suggests that development of totally new thin seam technology could yield great benefits.

3. Multiseams

The juxtaposition of rock and coal in a sedimentary sequence leads to two kinds of mining problems. If the strata are relatively thin, then a sequence of coal and rock layers may be mined as one unit (or seam) so long as the proportion of rock is small enough to be economic. Current practice averages 25 - 30% reject in dirty seams, with 50% rock being regarded as the outer limit of profitability. A higher proportion of rock leads to excessive machine wear, more intensive product preparation, and generally higher handling costs per ton of coal mined.

If the coal beds are more widely separated, and if each seam is thick enough to be mineable by itself, the removal of one coal may hinder the subsequent removal of another. These so-called multiple seams, although not widely mined in the United States, pose a multitude of operational problems which vary with the order in which the seams are removed. Such problems include roof falls, rib sloughing, floor heaves, water flooding, and disruption of the ventilation system. Contrary to popular opinion, removing the top seam first does not necessarily simplify the extraction of subadjacent seams. A choice between taking the top seam first, the bottom seam first, or mining the seams simultaneously is a complex function of overburden, seam thickness, roof and floor quality for each seam, and the structural strength of the rock mass between the seams.

The identification of multiseam resources required a reanalysis of the logs used to estimate tonnage for the more familiar resource categories. Table 2-6 places those results within the broader context of the aggregate national resource. This summary tabulation indicates that multiple seams comprise over 50% of the aggregate flat-lying coals of moderate thickness under less than 2000 ft of cover, and about 21% of the total resource. No attempt was made to isolate multiple seams within the categories of steeply dipping, thin, exceptionally thick, or very deep coal. However, one could safely assume that a similarly large proportion of these more challenging resource types may be classified as multiple seams as well. Examination of Table 2-6 reveals that almost 40% of the shallow multiple seams are concentrated in the Gulf Coast, with the remainder of this resource type spread fairly evenly over the other five provinces. Comparison of multiple seam and isolated seam tonnages indicates that multiple seams dominate by a factor of 1.5 to 3 in all provinces, expanding to a ratio of 5:1 or more in the High Plains and some basins in the Rocky Mountains.

These numbers must be considered order of magnitude estimates, since they depend upon a particular definition of a mineable unit and upon a particular quantification of the zone of interference, which is itself only the crudest approximation to a very complex reality. Perhaps the real import of

Table 2-6. Remaining Resources By Major Resource Category and Coal Province

(Tonnage is expressed in Billions)*

Province	Thick, Steeply Dipping, or Intruded; No Depth or Thickness Limitations**		Flat Lying, Under 180 in., and Below 2000 Ft.		Flat Lying and Above 2000 ft						TOTAL	
					14 - 28 in.		28 - 180 in.					
							Isolated Seams		Multiple Seams			
	Tonnage	Percent	Tonnage	Percent	Tonnage	Percent	Tonnage	Percent	Tonnage	Percent	Tonnage	Percent
Appalachian Plateau	0	0.0	28	0.2	239	2.0	244	2.1	298	2.6	809	6.9
Interior Basin	13	0.1	31	0.3	326	2.8	112	1.0	258	2.2	740	6.4
Gulf Coast	46	0.4	1865	16.0	191	1.6	686	5.9	998	8.5	3786	32.5
High Plains	63	0.6	14	0.1	56	0.5	72	0.6	402	3.4	607	5.2
Rocky Mountains	210	1.8	1462	12.6	65	0.6	97	0.8	358	3.1	2192	18.8
North Alaska	106	0.9	3149	27.0	32	0.3	68	0.6	160	1.4	3515	30.2
TOTALS	433	3.8	6549	56.2	909	7.8	1279	11.0	2474	21.2	11,649	100.0

*Tonnages may not add to totals shown elsewhere due to round-off.
**Steeply dipping beds of significance are found in the Rocky Mountains and the Interior Province, with an estimated tonnage of 12.4 billion.

these numbers is the light it sheds on the problem of coal conservation, and thus, the value of developing mining systems which minimize the impact on adjacent coals.

B. GEOLOGICAL TARGETS FOR ADVANCED MINING SYSTEMS

The results of this study offer clear guidance for the development of advanced mining systems to enhance the exploitation of U.S. coal and lignite resources. Firstly, there is strong evidence that the total resources have been underestimated by at least 100%, and that a substantial body of coal and lignite occurs at depths greater than 2000 ft. A large fraction of these deposits are found below depths where coal is currently mined in the United States, with the deep coals occurring mainly in the Gulf Coast and North Alaska, and to a lesser extent in the Rocky Mountain Province. The poorly consolidated character of the rocks in the Gulf Coast and the extreme depths of much of the North Alaskan coals suggest that utilization of these deeply buried resources is best accomplished by unconventional techniques, probably involving in situ comminution or conversion. However, the state-of-the-art in solution mining, in situ combustion, and related technology is not well developed, and benefits from these modes of exploitation appear likely only in the long-term.

Secondly, the data indicate that 1.2 trillion tons of resources lie within 500 ft of the surface, and thus, within the ordinary range of surface mining. These resources are roughly equally distributed across the coal provinces of the contiguous United States, and hence, comprise a readily available short-term resource. Extraction technology in this area is similar to that utilized in other excavation enterpises and has benefitted greatly from the transfer of technology. Although technological evolution may be expected to continue, development of totally novel surface extraction methods appears both unnecessary and unlikely.

Thirdly, these data indicate that substantial resources of bituminous and subbituminous coal occur at depths suitable for underground mining (less than 2000 ft), with shallow inclination, and absence of faults and igneous intrusions--all of which simplify underground operations. These bodies of coal occur mainly in the Rocky Mountain, Interior, and Appalachian Provinces where an infrastructure already exists for underground extraction. Within these areas, efforts toward the enhancement of extraction technology should be directed to seams in the range of 15 ft - 42 in. since only a small proportion of the resources occur in seams thicker than 15 ft. It appears that technological advancement in mining coals 15 ft - 42 in. thick would be best directed toward improving the capability of existing systems for the extraction of isolated (non-interfering) seams. However, a potential for major technological innovation exists in the recovery of multiple seam deposits and thin coals. The relatively small indicated tonnage of seams which can be mined in isolation has strong implications for resource conservation. As mining proceeds in Appalachia and the older coal fields of other provinces, depletion of the resource will occur at a rate much higher than may be apparent because of inattention to the mutual interference of closely adjacent coal beds. Accordingly, multiple seams are regarded as a resource of long-term national importance, and of short-term importance in those coal fields where mining has been intensive.

Finally, this study has shown that only a relatively small proportion of the U.S. resources occur in steeply dipping, faulted, or intruded bodies. Consequently, although some of this coal is of good to excellent quality, the technical problems associated with it, relative to the total volume available, place it in a position of secondary importance compared with coals that can be more easily extracted.

SECTION III

APPROACH TO SELECTING RESOURCE TARGETS

In this section three issues are discussed. First, a statement of the problem is given; second is an overview of the methods and data sources used in solving the problem; and finally, a summary of the methodology used in the economic analysis is provided.

A. PROBLEM STATEMENT

Suppose that an agency wishes to provide support to development of the basic technology used in the mining of underground coal. The problem faced by the agency is to decide which technologies should receive support. Since technology is generally designed to mine coal in a particular geological environment, the choice of technologies can and should be stated in terms of those geological parameters. This point needs some amplification. Suppose that thin coals (14 - 28 in. seams) are very large in quantity, spread all over the country, and are generally near markets. Whether these coals are the proper targets for the development of advanced extraction systems depends on whether there are alternative coals which could be brought to market at prices cheaper than the thin coals, given the same levels of expenditure on the development of advanced coal extraction technology. Whether this could occur will depend in part on how challenging the geological conditions are in which the alternative coal is found. Thus, the problem which this report addresses is the determination of which coals, as characterized by their geological surroundings, should be the targets for advanced coal extraction systems which are yet to be developed.

B. OUTLINE OF METHODS AND DATA SOURCES

This portion of the report includes three topics. First is an outline of the methods used in this study. The data provided by Energy and Environmental Analysis, Inc. (EEA) in a previous projection of regional coal prices is then described. Finally, the geological results of Section II are translated into generic resource types which will be examined in the subsequent economic analysis.

1. Outline of Methods

An outline of the procedure used for targeting coals is given now. The data base used in Regional Price Targets (Terasawa and Whipple, 1980) is modified through the specification of alternative demand scenarios, and the additional consideration of geologically significant coal resources not originally considered. These modifications add to the substance of the subsequent targeting decisions. An initial screening of these resources is then carried out, and the resources are narrowed down to the candidate coals. For the candidate coals, the cost savings which can reasonably be expected from the adoption of an advanced extraction system in each geological environment is obtained, and by applying targeting objectives, the choice of the resources to be targeted is made. An overview of the analysis is sketched in Figure 3-1.

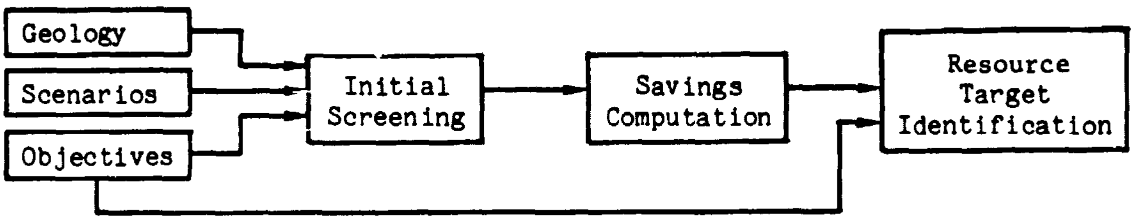

Figure 3-1. Analysis Overview

The analysis starts with a demand scenario and a geological description of the aggregate coal resources. A simple supply and demand model is used to allocate the coal to the various demand regions. At that point the following are known: the mine-mouth price of coals exploited; the flows of coal from supply regions to demand region; and the quantity of coal extracted by mine type, location, and sulfur content. The initial screening of the coal is then done to reduce the scope of the problem. The coals remaining after this screening, the candidate coals, are then analyzed in more detail. Finally, the targeting objectives are applied to identify resources appropriate for large scale research and development effort.

When the detailed analysis is done, the results obtained are dollars saved per year, assuming the new technology can reduce the price to certain levels. Then savings are calculated on the basis of the supply and demand model for the year 2000. The idea is that the savings are typical of the savings that would accrue to a new technology applied to the various coal types in the era of year 2000.

2. EEA/Regional Price Targets Data Base

The basic data upon which both the Regional Price Targets and the present work is based was generated by EEA (1980). Estimates were developed for:

(1) Regional coal demands by sulfur category for the years 1985 and 2000;

(2) The magnitude of coal resources by supply region, sulfur category, and various geologic parameters (including depth, seam thickness, method of access, pitch, and block size);

(3) The average cost of mining each class of the identified resources (called the Minimum Acceptable Supply Price, or MASP);

(4) The quantity of coal by sulfur category* to be mined in each region in 1985 and 2000, given the regional demands and the

*Sulfur content is divided into three categories: Compliance (1.2 pounds SO_2/MMBTU or less); Low Sulfur (1.2 pounds to 2.0 pounds SO_2/MMBTU); High Sulfur (above 2.0 pounds SO_2/MMBTU). NSPS II plants are assumed to choose the coal type and scrubber configuration which will minimize total coal costs including expenditures on scrubbing and transport.

cost of transporting the coal, under the assumption that the overall objective was to minimize the total cost of the nation's coal demands for the current (1980) technology.

Ease of access and apparent stripping ratio were used to partition the resources into large blocks suitable either for surface or underground mining. The geological parameters used to characterize the underground mine-type were overburden, seam thickness, pitch, block size, and entry method (drift or shaft).

It should be noted that the EEA analysis was considerably simplified by assuming which resources would be in production in the year 2000. Thus, there was no consideration of the extensive Alaskan coals or the voluminous Gulf Coast lignites. The steeply pitching seams are not accurately reported in EEA's work, since only regional pitch data were available. In addition, the EEA study did not generally include coals deeper than 2000 ft because it was not expected that coals beyond this depth would be exploited by the year 2000. The demand scenario used by EEA supports this claim. However, since advanced systems could conceivably be targeted to deeper coals, some work beyond EEA's analysis is required.

3. Additional Geological Data

Geological parameters and descriptions are important since they will impose constraints on the methods which can be used to extract the resources. For example, the extraction of thin seam resources will probably require a different technology than thick seams, and the technology developed for one may not easily carry over to the other. Thus, it is important to carry out the selection of additional candidate resources in terms of these geological parameters since the choice of resource, and hence geology, will play an important role in the development of advanced coal extraction systems.

To solve the targeting problem, the quantity and location of coals in the various geological classifications must be known. Examination of the character of geologically significant resources from a perspective of gross constraints on exploitation (see Section II) suggests a partitioning of the aggregate coal tonnage into the generic resource types presented in Table 3-1. Note than over 50% of the flat-lying coal above 2000 ft is in multiple seams of moderate thickness, with most of the rest of the tonnage in this category being split between thin seams and isolated seams having a large coal proportion. Thick coals above 2000 ft and abandoned pillars are minor resources in relation to the national aggregate.

One resource listed in Table 3-1, multiseams, is not often discussed in the literature. Multiseams are a commonly observed feature of a carboniferous sedimentary sequence wherein layers of coal and rock alternate in rapid succession. The spacing between seams and the fraction of coal in the excavated material are important mining considerations for such a resource. At one end of the spectrum are relatively thin layers of coal and rock (coal with partings) which may be removed as a unit and are often considered as one "seam" if the weight fraction of coal is high enough. At the other end of the spectrum are so-called multiple seams which are close enough to one another such that the removal of one may seriously constrain the removal of the other--be it above or below the first seam mined. Multiple seams and the subcategories of isolated seams are defined more precisely below.

Table 3-1. Summary of Resource Types for the United States*

Resource Type	Tonnage (Billions)	Percent
Flat-lying coal above 2000 ft:		
Seams 15 ft - 28 in.		
Multiple seams	2,500	21.4
Isolated seams with ≥ 75% coal	1,300	11.1
Isolated seams with < 75% coal	50	0.4
Abandoned pillars	30	0.3
Seams 28 - 14 in.	910	7.8
Seams thicker than 15 ft	310	2.6
SUBTOTALS	5,100	43.6
Flat-lying coal below 2000 ft:	6,500	55.5
Coal dipping more than 15°, faulted or intruded	100	0.9
TOTALS	11,700	100.0

*Source: Ferm and Muthig (1982).

(1) Separate seams: isolated seams which could be mined independently and contain a substantial proportion of coal:

- 28 - 180 in. thick
- at least 75% coal by weight
- exhibiting a ratio of interburden to seam thickness of 25:1 or more

(2) Coal with rock partings: isolated seams where coal and the intervening rock partings are removed as a unit:

- 28 - 180 in. thick
- less than 75% coal by weight

(3) <u>Multiple seams</u>: seams which are mineable separately, but are so close to one another that removing one seam will hinder subsequent removal of the other:

- 28 - 180 in. thick

- at least 75% coal by weight

- exhibiting a ratio of interburden to seam thickness of less than 25:1

The estimates given above are useful in that some resources not reported in the analysis by EEA are now represented--in particular, the Alaskan coals, the lignites, and the multiseam resources. However, these additional resources do not have associated with them the sort of mining cost estimates which were used in EEA's analysis of more familiar coals. Thus when the detailed analysis is done, the approach must be modified for those resources which are not included in EEA's work.

C. ANALYTICAL FRAMEWORK

The discussion of the analytical framework is broken into three parts. First, the process of calculating savings for a simplified case is discussed; second, an outline of the procedures actually used in the savings calculation is given; and finally, the methodology used to calculate the expected savings is developed.

1. Overall Methodology

The following analysis provides a way to determine the economic attractiveness of an advanced coal extraction system with given resource compatibility and cost characteristics. With the insights that this first step generates, a methodology is developed which will select the coals to which an advanced coal extraction system should be applied in more general settings.

Suppose that the mine types in a given supply region are ranked from low to high by MASP. The resulting curve is called a supply curve. A supply curve for a hypothetical supply region is given as in Figure 3-2. Assume that mines 2, 4 and 5 are underground mines of the same mine type, and that a new technology is developed which reduces the cost of mining these underground reserves. Then a portion of the supply curve would shift downward as shown in Figure 3-3, leading to a rearrangement of the supply curve so that the lower cost reserves come first. This altered supply curve is shown in Figure 3-4.

Consider the possible economic impact of the advanced technology. The decrease in price may not alter who gets the coal. In other words, the fact that certain coals are now cheaper may not broaden their market but rather cause these coals to be sent to the same demand region as before the new technology was adopted, but at a lower price. In such a case, the value of the advanced technology (in purely economic terms) is the amount saved on the coal purchased. However, if the <u>pattern</u> of coal use changes because of advanced mining technology, an additional impact is possible. The new technology could reduce the price sufficiently so that the extraction of some

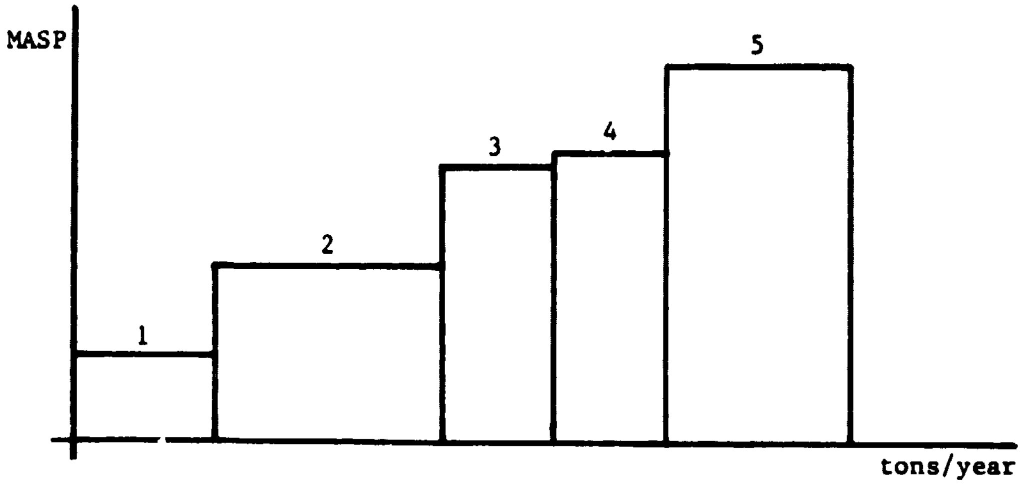

Figure 3-2. Supply Curve for a Hypothetical Supply Region

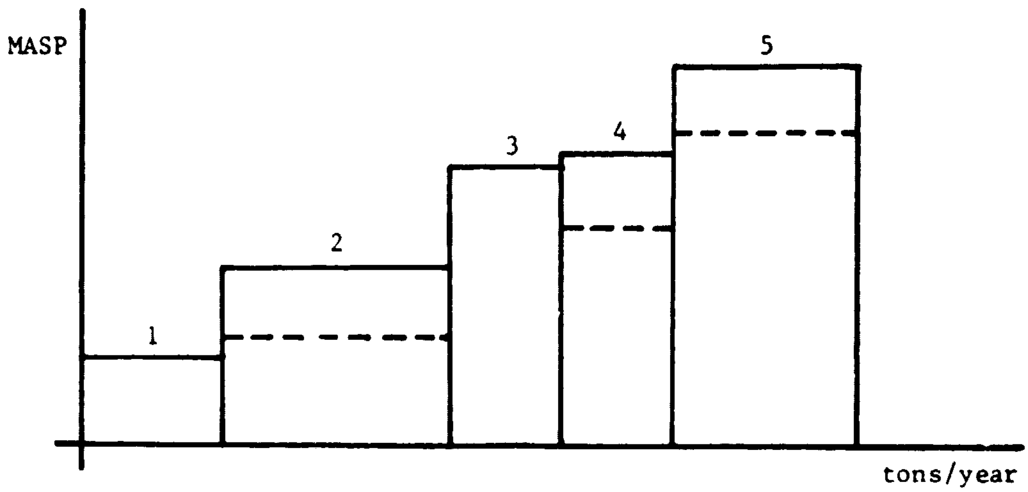

Figure 3-3. Hypothetical Supply Curve with MASP Altered by Technology

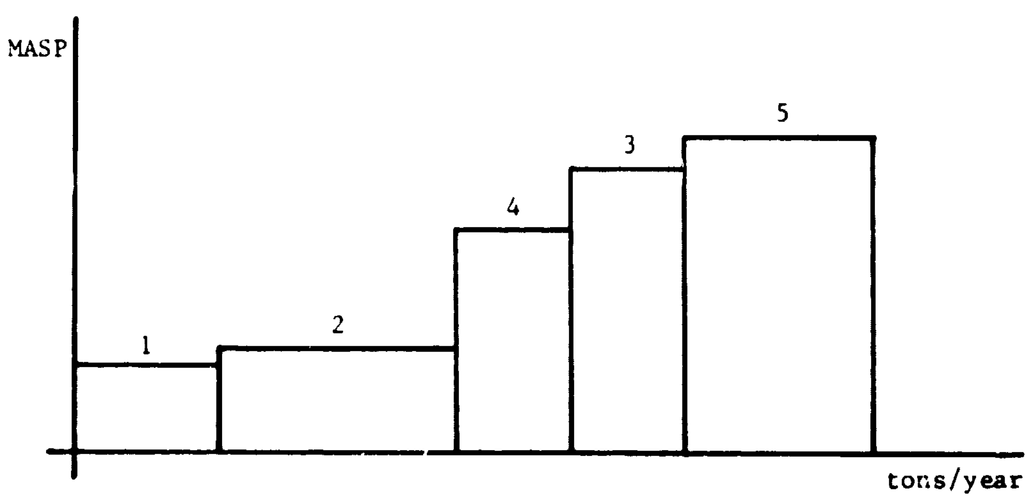

Figure 3-4. Supply Curve After Introduction of New Technology

surface coal would be reduced or eliminated entirely, such that there would be a net gain in underground coal production. In this case, in addition to the gains described above, there would be a gain equal to the difference between the price of the coal replaced and the price of the new coal times the quantity of new coal sold. Note that in each case, to compute the savings, both the new price and the price of the coal to be replaced must be known.

The principal difficulty in any such cost-benefit analysis is the determination of the price at which coal would be mined with the new, unknown technology. To partially deal with this problem, one could ask by how much the new technology would have to lower the MASP to make the coal from a given mine type competitive with the next lowest priced coal? By continuing this process, it is possible to determine the savings which would result from the reduction in MASP. To make these calculations, one needs to know only the quantity of coal in that minetype, the current MASP of that coal, and the MASP of the competitor coals. However, the final question would remain: to what level is it likely that the new technology could reduce the MASP? The answer to this question would require expert anticipation of the result of the design and development of new mining hardware. Thus, the methodology must determine the savings likely to result from fixed, assumed decrements to the estimated average mining costs (MASPs).

The savings from the commercial use of new technology can be calculated as follows. Assume that there is only one supply and demand region. Suppose that the supply and demand are given as shown in Figure 3-5; then the equilibrium MASP is $MASP_0$. Suppose that the coal targeted for the advanced technology is represented by 4 in Figure 3-5. If the advanced technology reduces the MASP of coal type 4 to $MASP_1$, the savings will be ($MASP_0$-$MASP_1$) times (Q_0-Q_1) tons of coal plus ($MASP'_1$-$MASP_1$) times the remaining amount of coal in mine 4, namely (Q_4-Q_0); where (Q_4-Q_0) = (Q_1-Q'_4) by construction. As the MASP continues to fall, assuming all of coal 4 is exploited at $MASP_1$, the additional savings due to reduction in MASP will just be the change in MASP times the quantity of coal in mine 4. In fact, this is the case for all resources being exploited in the absence of an advanced extraction system. If the advanced system is applied to some other resource--a resource not expected to be in production in the absence of an advanced system--it may be that no savings occur if the MASP cannot be reduced by an amount which would allow the new resource to become competitive. Even if the coal does become competitive, savings may not accrue to all units in that mine because at the new price, the mine may be only partially exploited. In short, the savings are calculated by multiplying the quantity of exploited coal sold times the difference between the current price for a mine type (or market MASP, whichever is lower) and the new price resulting from an advanced coal extraction system.

2. Savings Methodology

Below are the basic steps in calculating savings for resources analyzed by Energy and Environmental Analysis, Inc.

(1) Select a candidate coal and locate the supply regions in which that coal is found.

(2) Determine which supply region sends coals to which demand region, and what the delivered price is, by sulfur type.

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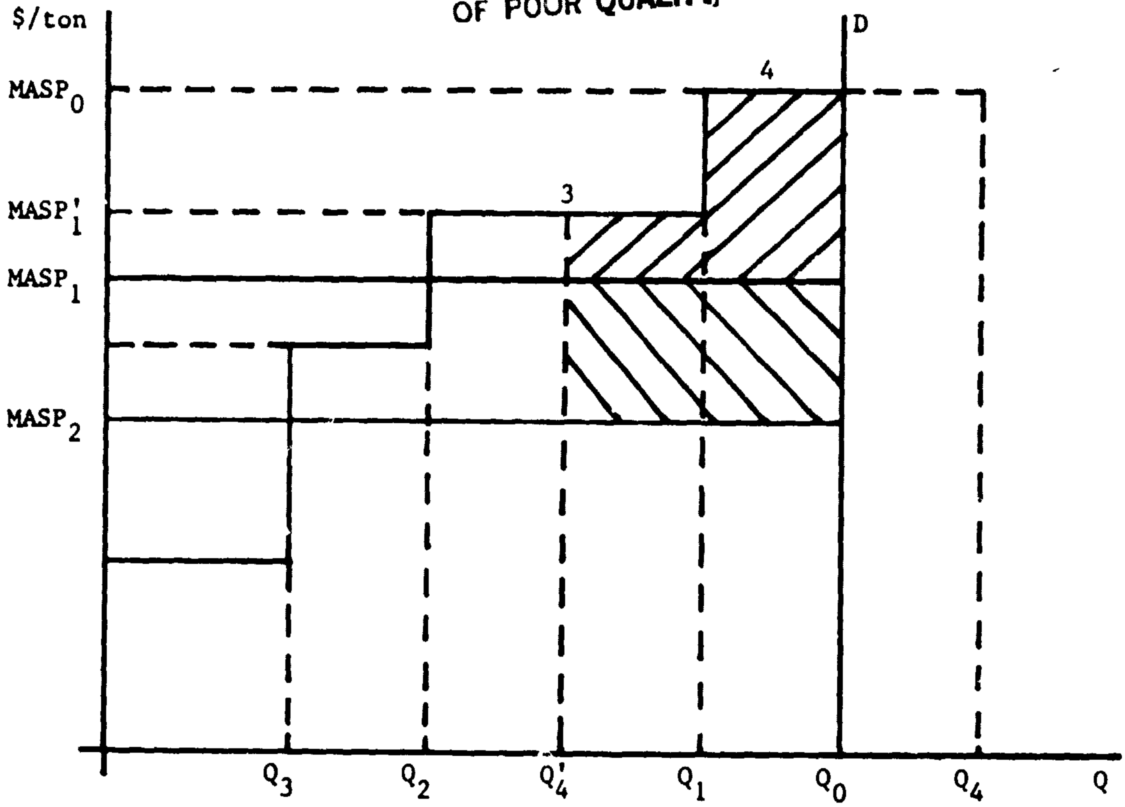

Figure 3-5. Hypothetical Supply and Demand Function for One Supply Region Serving a Single Demand Region

(3) Choose a demand region and subtract the transport cost from the prevailing delivered price in that region. This will give the mine-mouth MASP the candidate coal must beat to be competitive in that demand region. Allocate supply regions to demand regions on the basis of the difference between the MASP to beat and the MASP of the candidate coal not in production.

(4) For the supply region which is sending coal to that demand region, determine the amount of coal replaced by the candidate coal as the MASP of the candidate coal falls, and compute the associated savings.

(5) Repeat steps 3 and 4 for all demand regions and competitor coals.

(6) Aggregate the savings over all demand regions.

With minor adjustments, the above process can also be applied to resources not in EEA's analysis (e.g., North Alaskan coals and Gulf Coast lignites) even though the MASPs for these supplemental coals is not known. However, of necessity these supplemental coals must be treated more grossly than the coals considered in EEA's analysis. For example, a given mine type for a conventional resource may have several different MASPs within a region for coals of the same sulfur content. Thus, for coals in EEA's analysis, only that portion of the coal with a competitive price will be available for exploitation, whereas, for coals not in EEA's analysis, the entire amount of the coal for a given mine type is considered available for production if the MASP is low enough.

The savings calculation may be summarized as follows. Arrange the coals to be exploited from high to low by MASP; number them by assigning one to the mine with the highest MASP, two to the second highest MASP mine, and so on. Let i represent these mine numbers. The savings are then

$$\sum_{i=1}^{N} (MASP_i - MASP_0) \quad Q_{Ti}$$

subject to the following conditions:

$$MASP_i - MASP_0 > 0$$

$$\sum_{i=1}^{N} Q_{Ti} \leq Q_T$$

where

N	=	the largest i
$MASP_0$	=	the MASP of the candidate coal
Q_T	=	the quantity of the candidate coal available
Q_{Ti}	=	the quantity of the ith coal replaced by the candidate coal
$MASP_i$	=	the MASP of the ith coal

3. Calculation of Expected Savings

In the previous section, the procedure used to calculate the savings was described. That process produces a relationship between MASP and savings showing the savings that will occur if the MASP falls to a specified level. This information does not by itself solve the targeting problem. In order to know which coals to choose, the level of savings that is likely to occur needs to be determined. This piece of information would be available if the likelihood of occurrence of the various MASPs were known. Thus, to use the savings information generated above in a meaningful fashion, the probability density for the MASP is needed. Once this piece of information is available, the expected savings can be calculated and the choice process may proceed.

Since larger changes in MASP seem less likely than smaller ones, a truncated geometric density function was chosen which allows N+1 possible MASPs:

$$f(x) = \frac{P(1-P)^x}{1-(1-P)^{N+1}} \quad x = 0, 1, \ldots, N$$

where P is the probability that the new technology will be able to produce coal at a MASP high enough to mine the coal by conventional methods, and f(x) is the probability that the x^{th} change in MASP occurs.

Given this form of the density function, two alternative analyses of the expected savings are performed. In the first analysis, values for the parameters P and N are assumed, and the expected savings are calculated as a function of MASP. Additional values of P and N are used to determine the sensitivity of the expected savings to changes in these parameters. The second analysis determines the value of P required to achieve a specified level of expected savings for a given N.

Information about expected savings is combined with other factors in arriving at resource targets for R&D on advanced mining systems.

SECTION IV

RESOURCE TARGETING OBJECTIVES

A. INTRODUCTION

To determine which coals should be targeted for research and development depends upon selection of a set of objectives to be met by the program, of which the Advanced Coal Extraction System Project is a part. These are called the targeting objectives. This section of the report discusses the underlying assumptions and rationale, the objectives themselves, and likely implications.

B. ASSUMPTIONS UNDERLYING THE GOAL SPECIFICATION

In order to make more tractable the process of selecting a set of targeting objectives, four major assumptions concerning the nature and scope of the project have been made. In this section the assumptions are identified and a brief discussion of their foundation is given.

(1) Any advanced coal extraction technology must be "commercially attractive." The term "commercially attractive" means that there must be an inherent incentive for mining companies to adopt the new technology in place of its most desirable conventional alternative. This implies that the expected mining cost must have been "sufficiently reduced," compared with that of the conventional alternative technology. Here, "sufficiently reduced" implies consideration of the uncertainty associated with the adoption of any new technology.

Simply put, commercial attractiveness means that the expected profit associated with the use of the advanced technology, adjusted for risk, must be greater than that associated with the most attractive conventional technology. However the concern here is for long-run profitability (the year 2000 and beyond), which implies a time frame that is typically beyond the scope of the individual operator's planning horizon.

(2) Because of government sponsorship, long-run profitability should be the emphasis. Research and development (R&D) to enhance the short-run profitability of the individual mining operation is within the natural purview of the industry's member firms. An appropriate role for government is the funding of longer term, more uncertain, and probably capital-intensive R&D, which industry is generally not able to undertake.

(3) System requirements on miner health and safety, conservation, and environmental system requirements are indicative of additional targeting objectives. Although commercial attractiveness is the <u>sine qua non</u> for an advanced mining system, the previously developed system performance goals require a substantial improvement in miner safety and strongly encourage better performance in miner health, environmental impact, and the conservation of unmined coal. Note that these latter four considerations have to do less with the direct economic viability of an advanced system and more with

social concerns, or costs and externalities which are extremely difficult to quantify. However, their very existence poses constraints on the project's form and direction. Analysis of the potential impact of the proposed resource targeting in terms of the four companion systems requirements may help in choosing among targetable resources, each of which may appear to be commercially significant.

(4) Commercial attractiveness depends upon more than cost reduction. It must be recognized that coal is already relatively cheap in terms of available British Thermal Units (BTU), and that demand for coal is not larger due to concerns related, for the most part, to handling and applications. Thus, since advanced coal extraction technology will deal only with the possibility of reducing the cost of mining coal, the main impediments to expansion of the coal market may not be fully accounted for. This means that because the BTUs of energy that coal represents may not be suitable for all energy applications even if the price of coal falls, coal will not be commercially attractive in all applications.

These assumptions may be readily developed into a set of resource targeting objectives.

C. SELECTION OF THE OBJECTIVES AND THEIR RATIONALE

A large set of potential objectives were considered, analyzed, and discussed during the selection process. Overall they fell into two major categories:

(1) Macro Objectives: Those which dealt for the most part with impacts on, or concerns of, the country as a whole.

(2) Micro Objectives: Those which would more properly be the concern of geographic regions or specific interest groups.

Fortunately, the Advanced Coal Extraction Systems Project contains some inherent "screens" and "focuses" which significantly assisted in the selection process.

First, consider that the extraction technology to be developed is to be applicable to underground mining operations. This argues effectively against choice of coal export maximization as an overall, or primary, targeting objective. Had concern over the level of future coal exports been a major impetus in the project's birth, the decision to limit its resource targets to underground coals would appear ill-advised. This follows from the likelihood that a major increase in the demand for coal exports is most likely to come from the Pacific Basin, and in that case, the strippable sources in the western U.S. would be the most prominent candidates. Thus, given the requirement on commercial viability, and the fact that the western underground resources tend to be much more expensive to mine compared to surface coals, it was considered inappropriate to allow probable export levels to be a significant concern in the resource targeting decision, even though the salutory effect on U.S. balance of payments might appear extremely desirable.

Next consider the project's implementation time frame, that is circa the year 2000. The long run nature of the project tends to eliminate more short-run goals. As an example, it was suggested that some might look upon an advanced coal extraction system as an indirect means to mitigate the economic impact of an interruption in the U.S.'s supply of oil from the OPEC nations. This would have taken the form of targeting resources with the object of ensuring that the required increase in U.S. coal production (over normally forecast levels) be done at minimum cost. However, the long-term nature of the project dictated against such a goal choice, since it deals with short-run considerations.

The companion goals discussed in the third and fourth assumptions seem to dictate that the targeting objectives be consistent with their implicit areas of concern. However, the federal sponsorship of the project was taken as evidence that such regional and micro concerns should be incorporated only as secondary, not primary resource targeting objectives.

In light of the foregoing assumptions and related discussion, the primary objective guiding the resource targeting process should be:

(1) Maximization of the total reduction in the annual expected cost of coal to be extracted in the year 2000 time frame. Meeting this goal would tend to minimize that portion of the "energy bill" associated with the use of coal, while simultaneously increasing the relative attractiveness of coal vis-a-vis oil, gas, and other energy sources. To further elaborate, let m_{sg} denote the mine-mouth minimum acceptable supply price (MASP) of coal from region s in geologic environment g. If x_{sg} is the quantity mined of such coal, the total mine mouth cost, T, can be written as

$$T = \sum_{g} \sum_{s} m_{sg} \cdot x_{sg}$$

This equation may be readily interpreted by ignoring for a moment the impact of transportation costs. Since m_{sg} is inversely dependent upon the efficiency of the extraction technology used, the primary objective is to choose the geologic resource conditions for the advanced technology such that T is minimized for given values of the x_{sg}'s.

However, suppose that there exists more than one set of targetable resources (g_1 and g_2) which will lead to approximately the same expected reduction in the delivered cost of coal. Then the secondary objectives could be used as part of the choice process. More formally, suppose that targeting one set of geologic conditions g_i, yields an expected total cost T_i, while targeting a separate resource, g_j yields T_j. If $T_i > T_j$, the question is whether the difference is "worth it" in terms of differential achievement of reasonable secondary objectives. To help resolve this problem, three secondary objectives are now specified which address a wide range of situations.

(2) Ensure that the resources targeted are those associated with coal exploitation requiring relatively small capital investment, which might, therefore, be undertaken by smaller mining operations.

Given the recent trends toward fewer numbers of coal producers, and an increase in the size of the firms acquiring coal resources, concern has been expressed over the potential for diminishing competition in coal supply. Thus, in assessing the relative desirability of targetable coals (i.e., those which meet the commercial viability constraint because of significant cost reduction), it is appropriate to ask whether targeting one resource over another might have beneficial effects in fostering or maintaining a competitive posture in the supply of coal. For example, suppose one of the candidate resources were coal which was amenable to a caving type of technology, and that the technology likely to be developed would be of a highly capital-intensive nature. On the other hand, taking an extreme case to illustrate the point, suppose that the other resource consisted largely of abandoned pillars. (Remember that both resources are assumed to have passed all the preceding goal screens.) Additionally, assume that the likely technological advancements pertinent to the latter resource would tend to yield a relatively labor-intensive technology which would not require very large capital investments. Then, ceteris paribus, the latter technology would be preferable under this objective.

Considerable concern has been expressed about the social and economic impacts (including regional issues) of changes in location of energy industry. For example, in Appalachia, coal mine closings can cause substantial economic and social disruptions. In a different way, opening new energy sources in relatively virgin areas can lead to problems associated with rapid, largely unplanned growth. These two polar possibilities are considered in the next resource targeting objective.

(3) Ensure that the resources chosen for targeting are those which will minimize the regional economic and/or social disruptions associated with their development (unemployment, infrastructure requirements, etc.).

However, it may not be possible to forecast confidently such impacts twenty years in the future. Therefore, an additional secondary objective is offered.

(4) Select resources for targeting such that a maximum amount of strip coals expected to be in production will be "replaced" by coals from underground resources.

Given the concern over the environmental impacts of continuing to allow significant amounts of strip mining, especially in the West, the likelihood that the amount of surface mining will be reduced should be assessed for each potential target resource. Such concerns are exemplified by the almost ten year moratorium on opening new coal lease bids for government lands in the West. Since the federal government has a major influence on the amount of strip mining in the area, it is appropriate to consider the possibility that targeting resources for underground advanced coal extraction technology could reduce the pressure for such leasing.

In order to determine which coals will be candidates for analysis under the set of objectives identified above, the quantities of coal likely to be in production circa 2000 need to be estimated. Given the uncertainty induced by relying on a single such forecast, a range of demand scenarios is developed in Section V.

SECTION V

DEMAND SCENARIOS AND THEIR IMPACT ON REGIONAL SUPPLY

A. INTRODUCTION

The focus in this section is on the specification, and derivation of alternative demand scenarios and supply responses. Of particular interest is the effect of variations in demand on forecast regional production, by mine type. The reasoning is straightforward: If coal demand varies significantly from that forecast by EEA in the year 2000, or if the production to meet the forecast regional demands differs from that forecast in the EEA baseline study, there may be some impact on the choice of the resources targeted as the most likely "market" for an advanced extraction system.

To this end the relevant range of coal and total energy demand estimates is examined in order to choose two levels of coal demand with which to compare the EEA baseline demands. The likely impact of the demand on regional supply levels is then considered in order to calculate and identify the changes in estimated production (and production costs) from the various types of coal resources.

B. ALTERNATIVE DEMAND SCENARIOS

As indicated by the Office of Technology Assessment (1979, p. 34), "Depending on assumptions, modelers can produce scenarios for 2000 predicting anywhere from 60 to 190 quads of total energy demand". However, detailed consideration of large numbers of alternative demand and supply scenarios was far beyond the project's time and resource constraints. Rather, the approach taken was limited to bounding and investigating the possible outcomes in terms of "targeting sensitivity." Thus, the EEA demand scenarios and their associated production estimates were used as the "baseline," and two alternative demand forecasts were chosen. The likely scenarios upon which the demand forecasts could be based were identified, and the results were used to generate an alternative set of regional production level forecasts.

1. Comparative Demand Estimates and Underlying Scenarios

As indicated above, there is no shortage of demand candidates. Figure 5-1 graphically portrays a sample of the range of alternative forecasts of total U.S. energy demand in the circa 2000 time frame, and associated estimates of the portion of that demand likely to be filled by coal. It is clearly beyond the realm of feasibility to consider each of these forecasts individually. Moreover, this project does not require such an effort since the objective is only to test the sensitivity of the resource targets to the EEA baseline coal demand estimate for the year 2000. Further, the multiplicity of estimates for total energy demand is of interest because of the composition of the underlying scenarios.

The majority of studies and models used in forecasting energy demand incorporate assumptions concerning a common set of variables and elements:

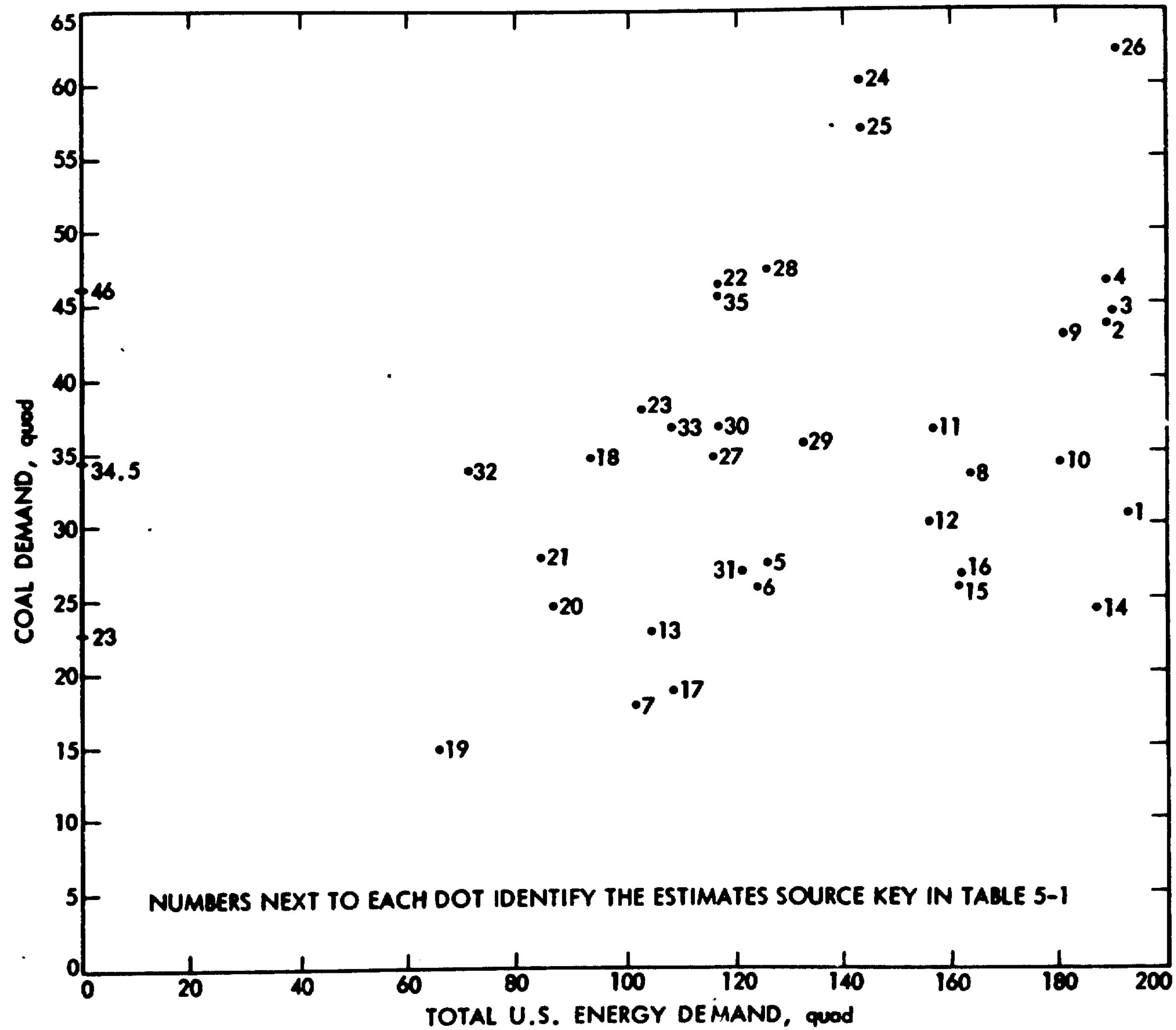

Figure 5-1. Estimates of Year 2000 Energy Demand: Total Demand vs. the Demand for Coal

(1) The rate of economic growth, or level of economic activity, as evidenced by the level of GNP or its rate of growth. These figures and their relative magnitudes for the world community as a whole and its individual member countries are also used in larger studies (see WAES, 1977b).

(2) The rate of growth of population, its absolute level, and demographics.

(3) The expected size of the labor force, the associated labor force participation rate, and the productivity of labor.

(4) The price of energy; the relative prices of oil, gas, etc.; and the price elasticity of demand.

(5) The availability of various fuel sources as well as their acceptability as a "replacement fuel."

(6) Policy and regulatory conditions which may hinder or facilitate changes in demand and supply, overall, or for specific fuel types.

It will be instructive to look at the way various sets of assumptions may be combined into scenarios which then "produce" (using modeling relationships) the estimates or forecasts of energy and coal demand. In Table 5-2 this is done for some of the scenarios generated by WAES, 1977b. Note that estimates of cases 28-31 in Table 5-1 resulted (partially) from the indicated combinations of world economic growth rates, oil and energy price levels, national policy responses, and most likely replacement fuels. For example, in WAES (1976) Case D-7 (Table 5-1, Case 30), the following assumptions were employed:

(1) low world economic growth between 1972 and 2000 (3.5% from 1972 to 1985, and 3.0% from 1985 to 2000);

(2) constant oil price of $11.50 per barrel (1975 dollars) between 1972 and 2000;

(3) a "restrained" policy of demand conservation between 1972 and 1985, and a vigorous policy after that (Tables 5-3, 5-4);

(4) coal used as the major replacement fuel for oil post-1985;

The resulting total energy demand in the year 2000 was forecast to be 115.1 quads; of which 37.5 quads were supplied by coal. Note that since the WAES effort was not one which generated a final equilibrium solution, this coal production is potential maximum production and does not necessarily mean all would be needed domestically. In fact, in the case D-7, 14.7 quads would be available for export. Actually, WAES Cases 28-31 in Table 5-1 contain export potentials of 18.1, 7.2, 14.7, and 8.6 quads, respectively. Thus, they might well serve as "high export" demand scenarios.

However, if the underlying WAES assumption of a $17.25 per barrel synfuel price is relaxed and the existence of only a demonstration program for such synthetic oil by 2000 is assumed, and if it is further assumed that additional

Table 5-1. Estimated Total Energy and Coal Demand: Sources and Quantities Circa 2000

Case Number	Total Energy	Coal Quads	Coal Market (%)	Source of Estimates; Scenario Used
1.	191.9	31.4	16	Dupree & West
2.	187.0	44.0	24	Energy Policy Project; Domestic, oil & gas
3.	188.0	45.0	24	Energy Policy Project; High Nuclear
4.	187.0	47.0	25	Energy Policy Project; High Imports
5.	124.0	28.0	23	Energy Policy Project; Self Sufficiency
6.	123.0	26.0	21	Energy Policy Project; Envir. Protection
7.	100.0	18.0	18	Energy Policy Project; Zero Growth
8.	163.4	34.8	21	Dupree & Corsentino
9.	179.1	43.5	25	EPRI; Case A, High Coal
10.	179.1	35.7	20	EPRI; Case A, High Nuke
11.	155.1	37.3	24	EPRI; Case B, High Coal
12.	155.1	31.0	20	EPRI; Case B, High Nuke
13.	104.5	23.9	23	EPRI; Case C
14.	186.2	28.6	16	DRI; Case A
15.	160.9	26.9	17	DRI; Case B
16.	162.5	27.5	17	DRI; Case B'
17.	109.5	19.5	18	DRI; Case C
18.**	93.7	35.0	37	DOE, MEFs
19.*	64.0	15.0	23	CONAES; I_2
20.*	85.0	25.0	29	CONAES; I_3
21.*	83.0	28.0	34	CONAES; II_2
22.*	115.0	47.0	41	CONAES; II_3
23.*	102.0	38.0	37	CONAES; III_2
24.*	140.0	60.0	43	CONAES; III_3
25.*	140.0	57.0	41	CONAES; IV_2
26.*	188.0	73.0	39	CONAES; IV_3
27.	115.2	35.8	31	WAES, Case D-7 (Excursion)
28.	124.5	48.0	38	WAES, Case C-1
29.	132.1	36.1	27	WAES, Case C-2
30.	115.1	37.5	33	WAES, Case D-7

Table 5-1. Continued

Case Number	Total Energy	Coal Quads	Coal Market (%)	Source of Estimates; Scenario Used
31.	120.3	27.5	23	WAES, Case D-8
32.	71.3	34.0	48	CONAES, S+D Panel, BAU
33.	106.6	37.2	35	CONAES, S+D Panel, E.S.
34.	151.2	75.0	50	CONAES, S+D Panel, N.C. (not shown on Fig. 5-1)
35.	115.1	46.9	41	EIA

Table Entry Sources:

Cases (1)-(8) , Gordon (1978), p. 56.
Cases (9)-(13), Gordon (1978), p. 51.
Cases (14)-(17), Gordon (1978), p. 50.
Case (18), DOE/MEFS (1980).
Cases (19)-(26), CONAES (1979).
Cases (27)-(31), WAES (1977a), pp. 60ff.
Cases (32)-(35), CONAES (1979), p. 568.

*Estimates are for 2010.
**Estimates are for 1995.

electricity generation is split 50:50 between coal and nuclear in the post-1985 time frame, the results of Case Number 27 in Table 5-1 are generated. Here, although total forecast energy demand remains almost constant at 115.2 quads (compared to 115.1 in D-7, Case 30), and potential coal production falls slightly to 35.8 quads, 31.7 of these quads are now demanded for domestic consumption, leaving only 4.1 as potential exports. In fact, potential exports for Cases 28-31, modified as above, would be 11.5, 0, 4.1, and 0 quads, respectively. The latter three cases might then be designated as low, or minimum, export scenarios and forecasts. It should be emphasized that the eight very different energy and coal forecasts just discussed were generated merely by varying the underlying assumptions. Obviously there are many combinations of assumptions which will generate a chosen demand level.

As another example, consider some of the combinations of energy conservation policy, energy prices, and GNP growth rates associated with various scenarios utilized by the Committee on Nuclear and Alternative Energy Sources (CONAES)* in constructing their estimates (Cases 19-26 in Figure 5-1 and Table 5-1). These combinations are presented in Table 5-5.

*Source: CONAES, (1979).

Table 5-2. Couplings of 1985 Scenarios to 1985-2000 Scenarios

1972-1985 scenarios	A	B	C	D	E
World economic growth[a]	high	low	high	low	high
Oil price[b]	high	high	medium	medium	low
National policy response	vigorous	vigorous	vigorous	restrained	restrained

1985-2000 scenarios	1	2	3	4	5	6	7	8
World economic growth[c]	high	high	low	low	high	high	low	low
Energy price[d]	high	high	high	high	medium	medium	medium	medium
Principal replacement fuel	coal	nuclear	coal	nuclear	coal	nuclear	coal	nuclear

[a] High, 6 percent; low, 3.5 percent.

[b] High, \$11.50 increasing to \$17.2; medium, \$11.50 constant; low, \$11.50 decreasing to \$7.66 per barrel of light Arabian crude FOB Persian Gulf in 1975\$.

[c] High, 5 percent; low, 3 percent.

[d] High, \$17.25; medium, \$11.50 (per barrel of oil equivalent).

Source: WAES (1977b), P. 343.

Table 5-3. WAES U.S. Supply Policy Assumptions 1972-1985

Fuel	Cases A, B, and C Vigorous Policy Response	Cases D and E Restrained Policy Response
Oil	Rapid outer continental shelf leasing	Delayed outer continental shelf leasing.
	Decontrol of crude oil prices in 1979.	Oil price controls on crude oil not removed by 1985.
	Tax incentives to promote secondary and tertiary recovery of crude oil.	No recovery incentives for crude oil.
Gas	Deregulation of new natural gas prices.	Natural gas price regulation continued.
Coal	Surface mining laws eliminate uncertainties about reclamation standards.	Reclamation uncertainties are not resolved soon.
	Federal coal lands leasing program is initiated immediately.	Delays continue in leasing of federal coal lands.
	Government provides assistance to railroads for coal transportation and grants rights to coal slurry pipelines.	Government does not assist expansion of transportation capacity.
Nuclear	Nuclear development is not seriously impacted by additional delays. Environmental and safety concerns about both reactors and the fuel cycle are resolved.	Environmental and sfety concerns continue to lead to delays and deferrals in nuclear capacity expansion.
Other	Government research, development, and demonstration programs including financial assistance for the commercializaion of emerging energy technologies, such as synthetic fuels, solar, and geothermal.	No additional federal assistance for massive development of alternative sources.

Source: WAES (1977b), P. 343.

Table 5-4. Definitions of National Policy Responses for U.S. Coal Scenarios

Policy area	Vigorous response	Restrained response
1. Surface mining laws	Debate over surface mining laws is resolved to eliminate the uncertainties about reclamation standards	Reclamation uncertainties are not resolved soon
2. Coal lands leasing programs	An effective coal lands leasing program is initiated by 1977	Delays continue in the establishment of an effective program to lease federal lands
3. Environmental impact statements	Government shortens the processing time of environmental impact statements to hasten the expansion stimulated by other government policies	Processing time of environmental impact statements does not improve
4. Air quality standards	Ambient air quality standards permit the burning of western coal without stack scrubbers	Stack scrubbers required for western coal
5. Miner/manpower training programs	Government supports a miner training program to meet industry's manpower requirements	Government does not support miner/manpower training programs
6. Labor productivity	Government assists in increasing miner productivity	Government does not assist in increasing labor productivity
7. Equipment productivity	Tax incentives are immediately created to induce industry to purchase more productive mining equipment	Tax incentives for increased equipment productivity are not instituted
8. R&D programs for mining techniques	Government supports R&D programs to improve mining techniques	No government-supported R&D programs for mining techniques established
9. Slurry pipelines	Governments grant rights of eminent domain to coal slurry pipelines to support coal transportation needs	Coal slurry pipelines continue to have right-of-way problems
10. Railroad transportation	Government provides assistance to railroads for their expansion and maintenance of capacity to ensure increased coal transportation capabilities	Government does not assist expansion of railroad's coal transportation capacity
11. Federal siting laws	Government streamlines authorization procedures for new plants and facilities	Present siting authorization procedures and delays continue

Source: WAES (1977b), P. 351.

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Table 5-5. Essential Assumptions of Demand and Conservation Panel Scenarios

Scenario	Energy Conservation Policy	Average Delivered Energy Price**	Average Annual GNP Growth Rate (%)
A'	Very aggressive conservation policy, resulting in substantially reduced demand and requiring some life-style changes.	4	2
A	Aggressive, aimed at maximum efficiency with minor life-style changes.	4	2
B	Moderate, slowly incorporating more measures to increase efficiency.	2	2
B'	Same as B, but with 3% average annual GNP growth.	2	3
C	Unchanged; present policies continue.	1	2
D	Energy prices lowered by subsidy; little incentive to conserve.	0.66	2

**In 2010 dollars as multiple of average 1975 price.

Source: CONAES (1979).

Thus far, only factors which determine the level of aggregate energy demand have been considered. Clearly, the determinants of the portion of that demand to be filled by coal is of major interest. The CONAES study assumptions regarding policies which would influence the fuel mix outcome are presented in Table 5-6. As indicated by Figure 5-1, these variations in scenarios and underlying assumptions resulted in a significant spread in the associated long-term coal demand forecasts. Likely bounds for these numbers will be developed in the following section.

2. Selection of Alternative Demand Forecasts and Scenarios

Consider the estimates of coal demand contained in Table 5-1 and shown in Figure 5-1. Note that, although these estimates range from 15 to 75 quads, they tend to fall mainly between 23 and 46 quads of demand for coal. Thus, these two levels were selected as the "lower" and "upper" bound demand levels respectively, and 34.5 quads was chosen as an intermediate demand level. The rationale for these choices is discussed below.

Table 5-6. Assumptions Specific to Energy Resource Estimates

Energy Source	Scenario[a] Business as Usual	Enhanced Supply	National Commitment
Coal	Production limited by difficulties leasing federal land; increasing costs and delays from lack of consistent environmental policies	Increased demand from enactment of consistent environmental policies	Rising worker productivity; availability of more capital; streamlined regulatory policies
Oil and gas	Price controls discourage domestic production; separate permits required for exploration and production in outer continental shelf; delays in leasing; withdrawal of public lands	Accelerated federal offshore leasing; lifting of controls on wellhead prices; streamlined permit processes; improved exploration and production technologies	Relaxation of Clean Air standards; streamlined procedures for environmental impact statements; federal loan guarantees for development and application of new technologies; federal return of withdrawn lands; assignment of priority status to materials and labor for oil exploration and recovery
Solar	No policies enacted to promote solar energy; solar energy finds few applications to 2010	Policies enacted to encourage some technologies (water heating and passive solar design); bioconversion only for municipal wastes; some central generation of electricity	National policy to foster the use of solar energy; federal intervention to accelerate development of demand; application of solar technologies required in new buildings and suitable industrial processes; mandatory conversion of municipal and agricultural wastes
Nuclear	No significant improvement in existing policies and practices: continuing uncertainty about waste disposal and reprocessing; no development work on advanced reactor concepts (except liquid-metal fast breeder reactor (LMFBR)); introduction of LMFBR stalled by unavailability of fuel and lack of sufficient preparation; higher prices for uranium	Major streamlining of regulatory policies to reduce time required for nuclear power plants and fuel cycle facilities; national policy favoring reprocessing and recycling of spent fuels; improved efficiency of light water reactors	Policies enacted to reduce uncertainties and streamline regulatory policies and practices; reprocessing and recycling of spent reactor fuel allowed; disposal of radioactive waste licensed and practiced; breeder development and demonstration accelerated and work sustained on other advanced reactor concepts

[a]Hydroelectric and geothermal projections not made on comparable bases. For geothermal energy, progressively higher projections imply progressively more favorable regulatory policies and industrial patterns, as well as more successful research and development. For hydroelectric generation, growth depends very little on the regulatory and financial climate, because the number of ecologically acceptable sites is limited.

Source: Compiled from National Research Council, U.S. Energy Supply Prospects to 2010. Committee on Nuclear and alternative Energy Systems, Supply and Delivery Panel (Washington, D.C.: National Academy of Sciences, 1979).

Note that the "baseline" coal demand in 2000, as estimated by EEA, is 46 quads. Figure 5-1 and Table 5-1 indicate that there are seven other forecasts from five separate sources, ranging from 44 to 48 quads. These are associated with forecast total energy demands of 115 - 125 or 180 - 188 quads. Thus the former group are predicting only medium growth in total energy demand (from an actual 78 quads in 1980) but a growth in coal's market share to approximately 35% (from 20% and 15.8 quads of coal in 1980); whereas, the latter group are predicting a much larger growth in total energy demand, but only a relatively small increase in coal's market share to about 25%.

Since the 46 quads of coal production is relatively high in light of the thirty-five estimates in Figure 5-1 (twenty-seven of the estimates are lower), it is appropriate to consider a level of coal demand between 46 quads and the lower bound of 23 quads. The intermediate figure of 34.5 quads appears reasonable, given that twelve of the estimates (from six different studies) fall in the neighborhood of this figure (31 - 38 quads). The associated changes in total energy demand range from a decrease of 10% (71.3 quads) to an increase of 146% (191.9 quads). The predicted levels of coal demand represent estimates of market shares ranging from 16 - 37%.

Figure 5-1 indicates that in the vicinity of the lower bound of 23 quads of coal demand, there are nine predictions of coal demand of from 23 to 29 quads from five different studies. These are associated with an extremely wide range of estimates of total energy demand: from a low of 82 to a high of 186 quads. The associated market shares run from about 33% down to 16%.

We believe that consideration of these three demand levels--46, 34.5, and 23 quads--spans the set of plausible year 2000 coal demands, and hence production, thereby permitting a very robust test of the sensitivity of resource targets to variations in the demand scenario. It is also important to understand the content of the scenarios under which such joint estimates of coal and total energy demand might be observed. This topic is addressed next.

It should be clear from the discussion of the preceding section that any number of combinations of assumptions collectively might "generate" a specific level of coal demand. Table 5-7 summarizes what some of these combinations might be for each of the three chosen levels of coal demand.

C. REGIONAL SUPPLY IMPACTS

The next step in the targeting process is to "allocate" these varying levels of demand to the supply regions, and within each region, among identified resource categories or "mine types". In particular, the likely geographic location of the demands for coal (Figure 5-2), along with the supply regions (Figure 5-3) and mine types most likely to be in production, must be determined. That is the subject of this section.

1. Allocation of Demands to Supply Regions

The first step is to determine the levels of regional demands corresponding to the forecast level of aggregate demand. The starting point is the demand levels forecast by EEA for the year 2000. The aggregate demand for 46 quads of coal was generated by estimating the demands for each of the

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Table 5-7. Underlying Scenario Possibilities Corresponding to Baseline, Intermediate, and Low Coal Demand Circa 2000

Chosen Coal Demand Level	Scenario	Sample Scenario Contents
46.0 (Baseline)	B-1	Moderate GNP Growth, Moderate Conservation, Moderate Energy Prices, High Exports, Government Support of Coal Switch
	B-2	High GNP Growth, Moderate Conservation, High Energy Prices, High Exports, Balanced Government Policy for Coal
	B-3	Low GNP Growth, High Energy Prices, High Exports, Government Support of Coal Switch
34.5 (Intermediate)	I-1	High GNP Growth, Effective Conservation, Balanced Government Support Coal vs. Nuke, Moderate Exports
	I-2	Moderate GNP Growth, Balanced Government Support Coal vs. Nuke, High Exports, High Energy Prices
	I-3	Low GNP Growth, High Energy Prices, Government Policy Support for Coal Switch, Moderate Exports
23.0 (Low)	L-1	High GNP Growth, Effective Conservation, Government Support for Nuclear, Moderate Energy Prices, Low Exports
	L-2	Moderate GNP Growth, Moderate Energy Prices, Balanced Government Support Coal vs. Nuke, Moderate Exports
	L-3	Low GNP Growth, High Energy Prices, Government Support for Nuclear, Effective Conservation

15 demand regions and aggregating. The relative sizes of these regional demands were based largely on forecast regional population changes which, in turn, influence the energy needed by the electric utility sector (see EEA, 1980). Thus, in order to generate the regional demand levels for alternative scenarios, the regional demands from the 46 quad baseline were decremented by 25 and 50%. Table 5-8 presents the regional breakdown for the 23 quad case. The analogous breakdowns for the 34.5 and 46 quad scenarios are 50 and 100% higher, respectively, than the figures in Table 5-8.

While it is reasonable that total demand changes by 50% (or 100%), it may not be reasonable that the demand in each demand region changes by the same percentage. Surely, if the cause of the increased demand for coal is higher oil prices, there is no reason to believe every demand region would react in the same way. For example, it may be possible that total demand increases by 50% if there is a permanent reduction in oil imports or if there is a moratorium on nuclear power. Yet the impacts on regional demands under those two scenarios would likely be quite different. Since the case of the 50% increase in demand is not specified here, there is no way to choose among the potential regional impacts, and hence, there is no *a priori* reason to skew the regional demands. Further, since in most cases the marginal MASPs do not change very much as demand increases, it is not clear that by changing the regional demands in other ways, far different marginal MASPs would result. This line of reasoning suggests that the error introduced by not considering the cause of the change in demand may not be significant.

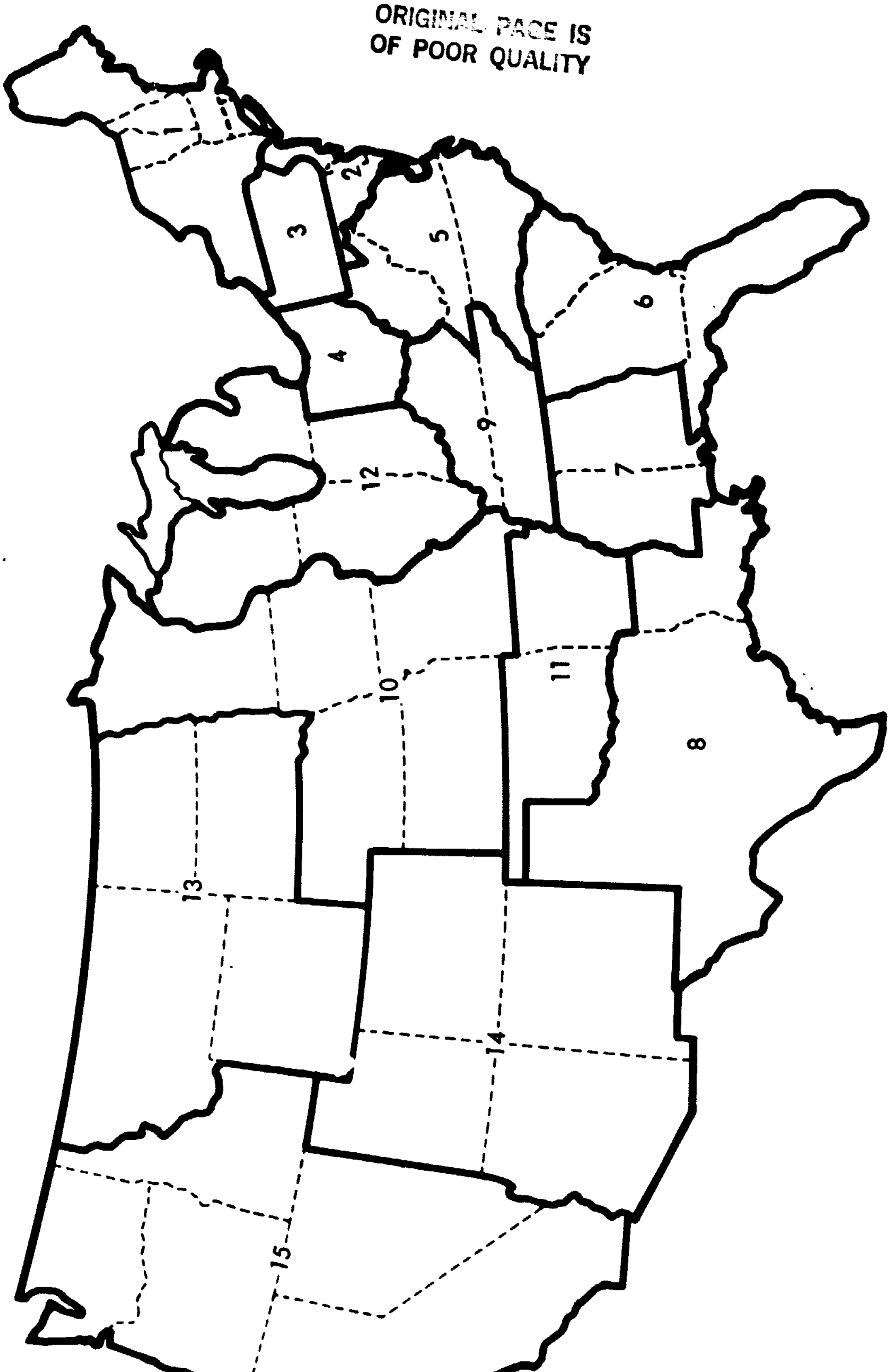

Figure 5-2. Regional Coal Demand Classification

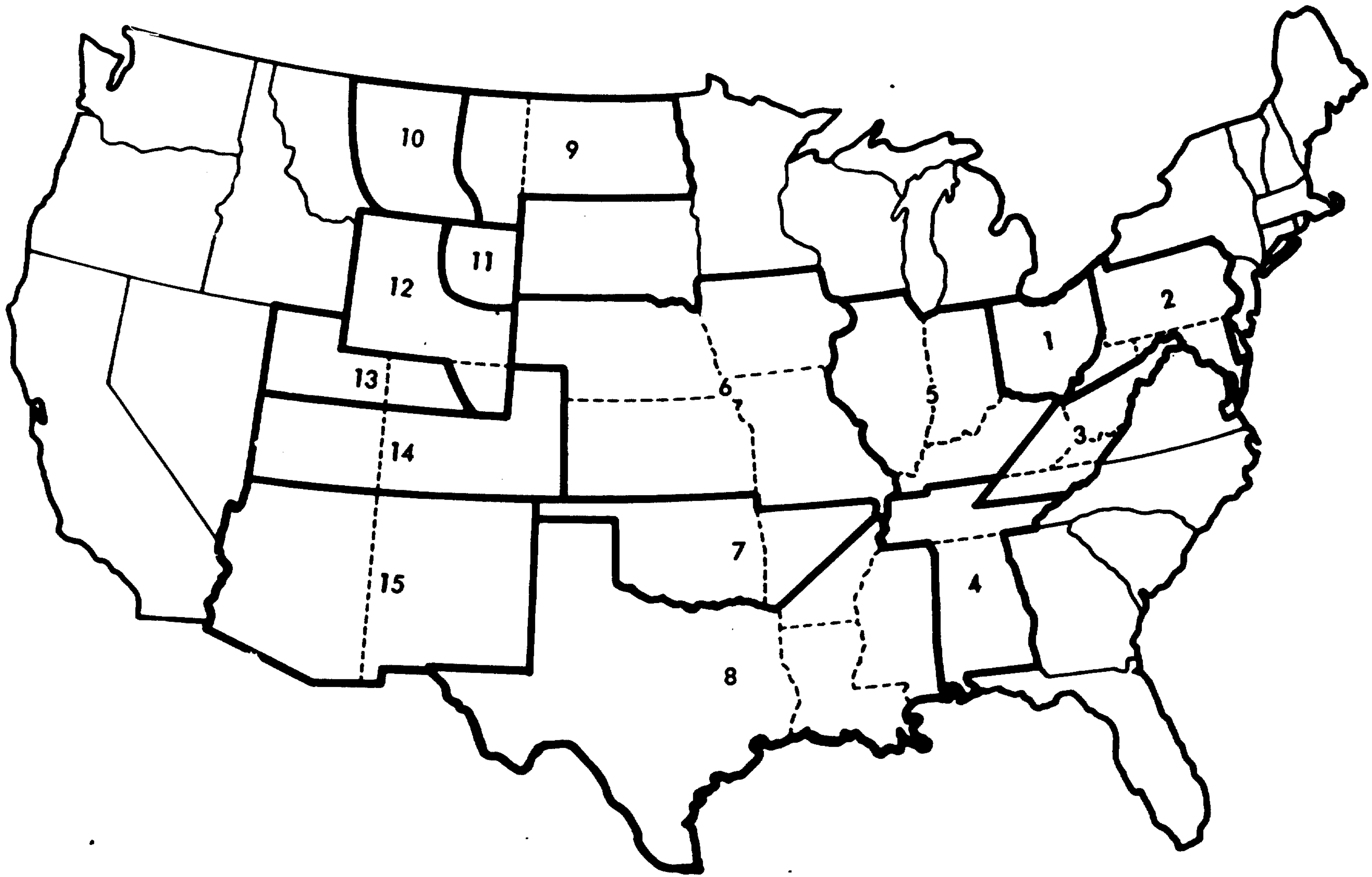

Figure 5-3. Regional Coal Supply Classification

Table 5-8. Regional Demands: 23 Quad Scenario (in quads)

Demand Region	Sulfur Category			Region Total
	Compliance	Low	High	
#1	0.180	0.442	0.128	0.750
#2	0.015	0.710	0.082	0.807
#3	0.372	0.305	0.527	1.204
#4	0.353	0.189	0.490	1.032
#5	0.711	1.525	0.338	2.574
#6	0.579	1.169	0.331	2.079
#7	0.170	0.259	0.328	0.757
#8	0.847	1.245	1.456	3.548
#9	0.136	0.762	0.644	1.542
#10	0.544	0.525	0.561	1.630
#11	0.396	0.233	0.204	0.833
#12	1.085	0.226	1.001	2.312
#13	0.158	0.371	0.244	0.773
#14	0.673	0.550	---	1.223
#15	0.548	1.677	---	2.225

So far in this study, it has been tacitly assumed that the coal is to be extracted as a solid. In situ conversion and solution mining methods have not been considered. Yet these methods are surely candidates for advanced mining concepts. It is useful to explain why these advanced technologies were not explicitly considered in this analysis. As Section VII explains, the savings for the coals included in EEA's analysis are calculated by allowing the MASP to fall in fifty mill/MMBTU increments and seeing which coals are replaced. Obviously, this calculation requires that the MASP (given the technology) must be known. Otherwise there is no reference MASP from which to calculate a decrease. Since in situ technologies are still in an early stage of development, it makes no sense to forecast MASP's for them circa 2000. Thus, methods similar to those used for coals not included in EEA's analysis would be needed to fully assess the relative competitiveness of in situ methods.

Yet the analysis does provide some information concerning the savings generated by non-traditional mining methods. First, the analysis of the resources not considered by EEA has broader technological implications. If the probability of bringing novel methods in at competitive MASPs is lower than the probability of reducing MASPs as a result of evolutionary change in traditional technology, the expected savings for a given coal type will be lower for the novel methods. Second, by considering diverse scenarios, several patterns of traditionally-based MASPs can be explored. Thus, there is the possibility that the traditionally-based MASP is the same as (or is near) the nontraditionally-based MASP in some scenario.

After regional demands had been determined, it was necessary to determine by sulfur category the source to "satisfy" each of the regional demands, for each of the three scenarios. In order to simplify the solution of this general market-equilibrium problem, the data from the two EEA forecasting efforts was analyzed to explore the stability of the links between centers of supply and demand. Table 5-9 summarizes EEA's forecast for how the regional demands will be satisfied.

Examination of these forecast supply-demand linkages via extensive sensitivity analysis revealed significant overall stability in the flows of coal from mine to market. More specifically, this analysis led to the following generalizations about flows of coal from supply regions to demand centers, with these generalizations being subsequently used to analyze the 34.5 and 23 quad scenarios. (The states associated with the demand region numbers are shown in Table 5-9):

(1) Regions #1 - #3 will buy their compliance coal from Central Appalachia (#3) and their low and high sulfur coal from Northern Appalachia (#2).

(2) Region #4 will use local (Ohio) low and high sulfur coal, and buy its compliance coal from Central Appalachian sources (#3).

(3) Region #5 will tend to satisfy all its demands through purchases of Central Appalachian coal (#3).

(4) Region #6 will increasingly rely upon Central Appalachian sources (#3) for its rapidly increasing needs for compliance and low sulfur coal.

Table 5-9. Supply to Demand Region Flows: EEA Baselines 1985 and 2000 (Quads)

Demand \ Supply	1 OH	2 WV, PA, MD	3 WV, KY,VA, TN	4 TN, AL	5 W.KY, IN, IL	6 KS, MO,NB IA	7 OK, AR	8 TX, LA	9 ND, MT	10 MT, PRB	11 WY, PRB	12 S.WY	13 N.CO, N.UT	14 S.CO S.UT	15 AZ, NM
1. N. Eng., NY	---	.55 .95	.3 .56	-	---	---	---	---	---	---	---	---	---	---	---
2. NJ, DE, MD	---	.29 1.6	.03 .03	---	---	---	---	---	---	---	---	---	---	---	---
3. PA	---	1.4 1.7	.6 .75	---	---	---	---	---	---	---	---	---	---	---	---
4. OH	1.0 1.3	---	1.0 .8	---	---	---	---	---	---	---	---	---	---	---	---
5. VA, NC	---	---	3.2 5.2	---	---	---	---	---	---	---	---	---	---	---	---
6. SC, GA, FL	---	---	.85 3.3	.4 .87	---	---	---	---	---	---	---	---	---	---	---
7. AL, MS	---	---	---	1.0 1.4	---	---	.25 .2	---	---	---	---	---	---	---	---
8. TX, LA	---	---	---	---	---	---	---	.8 2.9	---	.85 4.2	---	---	---	---	---
9. TN, KY	---	---	.2 .3	.3 .3	1.0 2.6	---	.22	---	---	---	---	---	---	---	---
10. KS, NB, IA, MN, MO	---	---	---	---	---	1.0 1.2	---	---	---	---	1.2 1.3	---	---	---	---
11. OK, AR	---	---	---	---	---	---	.08 .6	.03 .3	---	---	.65 .8	---	---	---	---
12. WI, IN, IL, MI	---	---	.44	---	1.4 1.1	1.0 1.4	.12	---	---	---	.08 .5	---	1.13 1.7	---	---
13. ND, SD, MT WY	---	---	---	---	---	---	---	---	.6 1.2	---	.26 .3	---	---	---	---
14. AZ, CO, UT, NM	---	---	---	---	---	---	---	---	---	---	---	---	---	.75 .75	.6 1.7
15. CA, OR, WA, ID, NV	---	---	---	---	---	---	---	---	---	---	---	---	.5 4.5	---	---

Source: EEA (1980).

(5) Region #7 will tend to buy its low sulfur and compliance coal from Southern Appalachia (#4), and its high sulfur coal from Oklahoma/Arkansas sources (#7).

(6) The significant increases in coal demand expected from Region #8 will be filled by local sources in Texas/Louisiana (#8) for high sulfur coal, and by Montana/Powder River Basin (#10) for compliance and low sulfur coal.

(7) Region #9 will significantly increase its dependence on the Illinois Basin (#5) for high and low sulfur coal, with its compliance coals coming from Central and Southern Appalachia (#4).

(8) Region #10's sources of supply will tend to remain stable, with its high sulfur coal coming from Region #6, and its low sulfur and compliance coal from the Wyoming/Power River Basin (#11).

(9) Region #11 will satisfy its high sulfur demand locally (Regions #7 and #8), and buy its low sulfur and compliance coal from the Wyoming/Power River Basin (#11).

(10) Demand Region #12 will narrow its suppliers to Regions #5 and #6 for high sulfur coal, the Wyoming/Power River Basin (#11) for low sulfur coal and the Unita region for compliance coal (#13).

(11) Regions #13 and #14 will buy all their coal locally.

(12) Region #15 will tend to buy from a single source--the Uinta region (#13).

These generalizations provided guidelines for the initial allocation of demands to the supply regions. However, before the allocation of demand could proceed, depletion of the coal sources included in the EEA baseline had to be examined.

The basic concern about depletion is easily expressed. The EEA baseline estimates of supply sources and associated MASPs did not contain any allowance for the possibility that some of the resource blocks might be nearing exhaustion circa 2000. Thus, any calculations of savings which utilize the EEA MASPs in conjunction with this study's demand scenarios could be biased as a result. Consequently, it was decided to calculate the alternative regional supply forecasts, <u>net of an approximation for regionally depleted resources</u>.

The estimate of the type and magnitude of the resources to be considered "depleted" in the year 2000 was based on the 1985 EEA regional production forecasts and assignments to mine types. Specifically, it was assumed that any mines forecast by EEA to be producing in 1985 would be "mined out" by 2000 or shortly thereafter, and their yearly productive capacity was not included in subsequent regional supply calculations. Table 5-10 contains these aggregate regional depletion estimates by sulfur category.

Operationally this meant that, of the 46 quads of production forecast to be forthcoming from the resources identified by EEA in their year 2000 scenario, 23 quads of capacity were assumed to be essentially depleted.

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Table 5-10. Regional Depletion Estimates: Year 2000

Supply Region	Quads of Coal Depleted			
	Compliance	Low	High	Total
#1 Ohio	---	0.153	0.863	1.016
#2 N. Appalachia	---	0.919	1.284	2.203
#3 Cen. Appalachia	3.446	2.518	0.702	6.666
#4 S. Appalachia	0.275	1.000	0.377	1.65[illegible]
#5 Illinois Basin	---	0.435	1.904	2.339
#6 Central Midwest	---	---	2.005	2.005
#7 Oklahoma-Arkansas	---	0.465	0.223	0.688
#8 Texas-Louisiana	---	---	0.872	0.872
#9 MT, ND Lignites	---	0.392	0.177	0.569
#10 Power River, MT	0.848	---	---	0.848
#11 Power River, WY	1.918	0.284	---	2.202
#12 S. Wyoming	---	---	---	---
#13 Uinta, Utah	1.367	0.266	---	1.633
#14 Four Corners	0.150	0.598	---	0.748
#15 San Juan	0.603	0.021	---	0.624

Thus, for the purposes of this study, the EEA 2000 regional supply forecasts were actually associated with a net aggregate demand of 23 quads, or with the "low" demand scenario. In order to generate the effect on regional supply of a 46 quad demand level, it was necessary to take the additional regional demands associated with the extra 23 quads of total demand, and allocate these demands to mine types not originally forecast by EEA to be in production circa 2000. Thus, the regional demand magnitudes shown in Table 5-8 had to be allocated among the supply regions. (The regional supply estimates for the 34.5 quad intermediate scenario were analogously derived.)

The actual process of allocating demand required the following steps:

(1) For each demand region, consider the incremental production needed by coal type and allocate it to the likely source identified in the analysis described in association with Table 5-9 (i.e., in accord with the patterns established by EEA's year 2000 forecast).

(2) Check the resulting pattern of MASPs to determine whether another region became competitive as a result of differential increases in the MASPs with increased production. This clearly depended on the relative transportation costs.*

(3) If difficulties were encountered in Step (1) due to resource depletion, or in Step (2) due to significant changes in relative prices, a reallocation of the demand quantity was made based on lowest delivered price (MASP).

(4) Analyze the resulting overall relative price pattern to determine the reasonableness of outcome, i.e., were there cases where the delivered price of coal could obviously be beaten by a competitor coal?

2. Results of the Allocation Process: Forecast Regional Supply and Costs

In only a few cases were Step (3) reallocations required due to resource depletion or non-competitive prices. In particular,

(1) The low sulfur demand from Region #4 had to be allocated to Central Appalachia (#3) rather than to Supply Region #1 due to depletion in Region #1;

(2) The compliance demand from Regions #6 and #7 had to be satisfied by Central Appalachia (#3) rather than Southern Appalachia (#4) due to depletion.

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*The transportation costs used were the estimates made by EEA (1980). These were converted from "dollars per ton" to "mills per million BTUs" to facilitate this analysis.

(3) The low sulfur demand from Region #6 had to be totally satisfied by Central Appalachian coals due to depletion in Region #4.

(4) Region #7's high sulfur demand had to be reallocated to the Illinois Basin (#5) due to depletion in Southern Appalachia, and the non-competitive price of Region #7's high sulfur coal.

(5) The compliance demand from Region #8 had to be allocated to the Uinta Region (#13) due to the non-competitive price of Region #10 coal on the margin.

(6) The high sulfur demand from Region #11 had to be reallocated to Region #6 from Region #7 due to the non-competitive price of high sulfur coal from Region #7.

Tables 5-11 and 5-12 contain the results of the demand allocations for the three demand scenarios. These production volumes and marginal MASP figures play an integral part in the calculation of potential savings under the alternative targeting choices which are discussed in Section VII.

Table 5-11. Forecast Regional Supply Levels and Marginal MASPS:
23 Quad Demand Scenario
Quads and (Mills/MM BTU's)

Supply Region	Compliance	Low	High	Total
#1	-----(----)	0.158(1317)	0.118(916)	0.276
#2	-----(----)	1.800(1284)	0.191(1002)	1.991
#3	1.245(1194)	2.348(1194)	0.547(1159)	4.140
#4	0.067(1464)	0.552(1189)	0.201(1157)	0.820
#5	-----(----)	1.091(1178)	0.032(982)	1.123
#6	-----(----)	-----(----)	0.472(755)	0.472
#7	-----(----)	0.000(749)	0.062(749)	0.062
#8	-----(----)	-----(----)	2.330(856)	2.330
#9	-----(----)	0.349(468)	0.312(468)	0.661
#10	0.845(518)	2.396(518)	-----(----)	3.241
#11	0.786(483)	0.000(481)	-----(----)	0.786
#12	-----(1432)	-----(1432)	-----(----)	-----
#13	1.389(1034)	3.088(1034)	-----(----)	4.477
#14	0.000(570)	0.000(559)	-----(----)	0.000
#15	0.593(676)	0.480(656)	-----(----)	1.073
TOTALS	4.925	12.262	4.265	21.452

Table 5-12. Forecast Regional Supply Levels and Marginal MASPS: 34.5 Quad Demand Scenario Quads and (Mills/MM BTU's)

Supply Region	Compliance	Low	High	Total
#1	-----(----)	0.158(1370)	0.363(939)	0.521
#2	-----(----)	2.529(1380)	0.782(1022)	3.340
#3	2.503(1350)	3.790(1433)	0.660(1304)	6.953
#4	0.067(1464)	0.682(1341)	0.224(1220)	0.973
#5	-----(----)	1.471(1280)	0.518(1024)	1.989
#6	-----(----)	-----(----)	1.355(816)	1.355
#7	-----(----)	0.116(1209)	.062(749)	0.178
#8	-----(----)	-----(----)	3.058(1329)	3.058
#9	-----(----)	0.534(468)	0.434(468)	0.900
#10	0.845(518)	3.019(518)	-----(----)	3.864
#11	1.335(483)	0.375(481)	-----(----)	1.710
#12	-----(1432)	-----(1432)	-----(----)	-----
#13	2.628(1140)	3.926(1072)	-----(----)	6.554
#14	0.000(570)	0.000(559)	-----(----)	-----
#15	0.929(1033)	0.755(656)	-----(----)	1.684
TOTALS	8.307	17.355	7.456	33.180

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Table 5-13. Forecast Regional Supply Levels and Marginal MASPS: 46 Quad Demand Scenario Quads and (Mills/MM BTU's)

Supply Region	Compliance	Low	High	Total
#1	-----(----)	0.158(1317)	0.609(950)	0.767
#2	-----(----)	3.258(1533)	1.485(1022)	4.743
#3	3.761(1707)	5.232(1819)	0.660(1350)	9.653
#4	0.067(1464)	0.812(1464)	0.224(1189)	1.103
#5	-----(----)	1.852(1307)	1.004(1024)	2.856
#6	-----(----)	-----(----)	2.238(816)	2.238
#7	-----(----)	0.232(1463)	0.062(749)	0.294
#8	-----(----)	-----(----)	3.786(1329)	3.786
#9	-----(----)	0.719(468)	0.556(468)	1.275
#10	0.845(518)	3.642(518)	-----(----)	4.487
#11	1.884(483)	0.750(481)	-----(----)	2.634
#12	-----(1432)	-----(1432)	-----(----)	-----
#13	3.867(1150)	4.764(1072)	-----(----)	8.631
#14	0.000(570)	0.000(559)	-----(----)	-----
#15	1.265(1033)	1.030(676)	-----(----)	2.295
TOTALS	11.689	22.449	10.624	44.762

SECTION VI

INITIAL RESOURCE SCREENING

The variety of coal resources which are potential candidates for targeting and the complexity of the savings calculations dictate that an initial screening be done to determine which candidates for targeting should be analyzed in depth. This section starts by discussing the basis for the initial screening, proceeds to an identification of resources to be screened, and then presents the results of the screening process.

A. BASIS OF THE SCREENING PROCEDURES

As detailed in Section IV, the primary objective to be satisfied is the minimization of the cost of the coal required to meet projected national demand under each of three demand scenarios. This goal may be restated as the desire to maximize the savings in the total expected cost of such coal as a result of the development of advanced coal extraction systems tailored to particular geologic environments.

For this reason the major criterion for ranking the resources, and thus for determining which coal should be removed from active consideration, will be the expected savings* likely to result from targeting these resources for R&D efforts. Because the initial screening is oriented only to order of magnitude comparisons, three categories of expected savings are recognized:

Category I: Resources for which an *a priori* judgment cannot be made that their expected savings will be small or uncertain.

Category II: Resources for which factors can be identified which *may* indicate relatively low expected savings.

Category III: Resources for which there is *strong* evidence to support a relatively low level of expected savings.

Coals in Category I will be singled out for detailed analysis because they are believed to be the resources most likely to generate the largest savings. Coals in Categories II and III are expected to produce substantially lower savings, and so will not be subjected to detailed study.

Simply put, the expected savings associated with the targeting of a resource, E, is equal to the size of the savings, S_j, times the probability of such savings, P_j, summed over j's, where the set of all j's is the number of incremental changes in MASP. This may be written:

$$E = \sum_j P_j S_j$$

*Expected annual savings circa 2000 will be used as a measure since the bulk of coal production is sold under long term contract.

The size of the savings to be realized depends directly on the physical quantity of the resource, r_j, and varies inversely with both the transport costs associated with its geographical location, t_j, and the existence of low priced competitor coals, R_k, as well as the technology available for extracting the coals, a. Thus, one can rewrite expected savings as:

$$E = \sum_j P_j S_j(r_j, t_j, R_k, a).$$

The technology, represented by a, can be used with some additional economic variables to determine the MASP. Moreover, the technology is expected to change (that is the essence of this project). Thus S_j, and hence E, will be smaller as:

r_j is small

t_j is large

R_k is large

Factors which indicate small savings imply small expected savings even if the probability of their occurrence is high (i.e., close to one); consequently, resources with such features will be assigned to Category III, those least likely to be targeted. Of course, all resources could exhibit small expected savings so that placing some coals in Category III just because they have low savings (S_j) might remove the best alternative from consideration. This will not be a problem if some coals exhibit large savings as is actually the case. There are basically two reasons for low savings (S_j): 1) a limited amount of tonnage, and 2) distance from market. In the first case, a small resource yields small S_j, since S_j is proportional to the size of the resource. Thus the probability of success of the new technology must be much higher to achieve the same expected savings. If a resource is far from markets relative to competitor coals, the advanced technology must provide for overcoming the transport cost differential.

Similarly, note that the probability of achieving any given level of savings varies inversely with the existence of geological constraints, and with recent technological advances in mining, a. That is, if the resource is found in such confounding geological conditions that satisfactory low cost mining methods are unlikely to appear, or if the nature of recent improvements in the technology suggest that there is a small chance that further improvements can be made, P_j, and hence E, will be small. Resources fitting this description will be placed in Category II as being more likely to be targets than those in Category III, but still not the most likely candidates. This decision stems from the fact that while there is uncertainty concerning the likelihood that any level of savings can be achieved for some coals, it seems a priori true that the MASP is unlikely to fall by enough to give a large expected savings. These coals may have a respectable amount of savings for some larger reductions in MASP but the probability of attaining these reductions in MASP are so small that expected savings will also be small. This case should be contrasted with the situation of Category III coals, where the savings are small for all reductions in MASP. The difference is that because of the small size of the resource (or distance from market), there is greater certainty that Category III coals will not provide the level of expected savings predicted for Category II coals. Should some combination of Category

III and Category II characteristics be associated with a specific resource, a determination will be made as to the most appropriate categorical assignment.

In summary, it is resources not falling into either Categories II or III which will be assigned to Category I in this initial screening. This is appropriate since if there is no a priori reason to suspect that expected savings will be low, the coal resource should be the subject of the more detailed analysis.

B. THE RESOURCE TAXONOMY FOR INITIAL SCREENING

As discussed earlier, the geological data are described mainly in terms of the following parameters: the thickness of the coal; the depth of the coal; the total tons available to be mined, and the pitch of the coal. Of these, seam thickness, depth of coal and pitch are the parameters most likely to affect the technology to be developed. Table 6-1 depicts the United States resource base in terms of these three variables.

The first three coals listed differ only in seam thickness. All are 2000 ft or less from the surface, and all are flat-lying. All coals deeper than 2000 ft, regardless of pitch and seam thickness, are reported in the deep coal category. All coals dipping more than 15^{o} are listed in the steeply dipping category. Resources in abandoned pillars have been deleted because of the small indicated tonnage. Because of the enormous tonnages in North Alaska, the High Plains, and the Gulf Coast, Table 6-1 also provides a breakdown by geographic location. Note that North Alaska contains about 30% of the coal resources in the United States, and 90% of the North Alaskan resources are deep. The lignite of the Gulf Coast and High Plains account for about another 40% of the resource, of which 40% is deeply buried.

The coals labeled "conventional" deserve more comment. The term conventional applies to the thickness and dip of the coal. Note that these coals can be further subdivided into seams that are strippable and seams which must be removed by underground methods. Further, to expect one advanced system to be able to mine any coal from 28 - 180 in. may be unrealistic. Finally, both the entry method and the potential mine size may be relevant considerations. Many of these issues will be addressed in the recommendation of R&D targets.

C. INITIAL SCREENING OF THE RESOURCES

The resources listed above in Table 6-1 can now be screened to identify the coals for which estimates of detailed cost savings analysis will be made. Category III (least attractive) coals will be discussed first.

A coal is assigned to Category III if it is very small compared with other resources or is too far from market. The Brooks Range Alaskan coals are likely to be too far from markets. For these coals to be competitive, they must be mined at prices comparable to strip-mined coal in the Western United States. Even in the Pacific Rim export market, perhaps the most likely market for the Alaskan coals, it is not likely that these coals will be able to compete with Australian, South African, or Canadian coals by the year 2000. Note that this argument is regional in nature. The main impact is to remove all North Alaskan coals from further consideration. Of course, should the

Table 6-1. Breakdown of Major Resource Types by Geographic Location (Billions of Tons)*

Class	North Alaska	Gulf Coast & High Plains***	Remainder of the U.S.	Total
Conventional seams** 28-180 in. flat, less than 2000 ft deep	298	2149	1298	3745
Thick seams greater than 180 in. flat, less than 2000 ft deep	23	109	183	315
Very thin seams less than 28 in. flat, less than 2000 ft deep	45	256	655	956
Deep seams Any coal greater than 2000 ft deep	3149	1879	1521	6549
Steeply dipping seams Any coal whose dip exceeds 15^{o}, or is faulted or intruded	0	0	124	124
Total National Resource:	3515	4393	3781	11689

*Source: Ferm and Muthig (1982).

**Note that the tonnage for conventional coals includes the tonnage for the resource types previously defined in Table 3-1 as multiple seams, separate seams, coal with rock partings, and abandoned pillars.

***All of the resource in the High Plains and Guf Coast is of lignite rank.

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final targeting apply to mining conditions also found in Alaska, there is no apparent reason why such a technology could not be adapted to the Alaskan resources (For a detailed argument supporting this point of view, see Appendix A.)

Abandoned pillars and steeply pitching coals are also candidates for assignment to Category III. Each exhibits an aggregate tonnage which is at least a factor of four smaller than any other resource type and would, therefore, require an inordinate reduction in mining cost to generate savings associated with coals present in much larger amounts. In addition, at least one rather attractive system for steeply pitching coals is commercially available.

Consider now the coals which might be assigned to Category II. Recall that the coals in this category are those for which the likelihood of technological advance (and hence change in MASP) is small either because the coal is in difficult geological surroundings or because there have been recent efforts at development of advanced systems elsewhere.

One group of coals for which development of an advanced system is unlikely are the thin coals and the closely related resource type--coal with rock partings. Seam height is an extremely important determinant of mining cost, especially when the seam becomes thin. The probability of reducing the costs of mining these thin seams to competitive levels appears low. In addition, there is a substantial resource of moderate thickness which can be mined with much less difficulty. Thus, for several reasons, thin seams and coal with rock partings are not likely to be attractive in terms of their potential savings.

Another resource which falls into Category II is the underground lignites. These coals have a heating value that is typically two-thirds that of bituminous coals. Thus, even though these coals are located in an area with a large growth potential, they are judged not to be important outside of that area because of the relatively high transportation cost per ton of delivered product. In addition, these coals are dominated by surface minable deposits. A more detailed analysis of these coals is presented in Appendix A. The lignites could be put in Category III. Finally, the very deep coals are Category II since foreign technology already exists to mine these coals, and given the quantity of shallower coals, these deep coals are unlikely to be extracted within the time frame addressed by this study. In one sense, they are too far from the market and could be considered Category III coals. In summary, thin coals, coal with rock partings, lignites and deep coals are in Category II. All remaining coals are, therefore, assigned to Category I. The results can be summarized as follows:

Category I	Category II	Category III
- Thick Seams	- Very Thin Coals	- Alaskan Coals
- Multiple Seams	- Coal with Rock Partings	- Abandoned Pillars
- Conventional Seams	- Lignites	- Steeply Dipping Seams
• thin, drift	- Deep Coals	
• thin, shaft		
• medium thick, drift		
• medium thick, shaft		

As indicated in Table 6-1, which provides formal definitions for the resource types analyzed in this study, the resource category called "conventional seams" overlaps (includes) multiple seams, separate eams, coal with rock partings, and abandoned pillars. Table 3-1 reveals that the two latter resources are insignificant. However, the "multiple seams" and "separate seams" portions of conventional coals are important enough to warrant additional scrutiny.

Note that flat-lying coals of moderate thickness are broken down by seam height and by method of entry. The thin coals are 28 - 42 in., the thick coals are 42 - 119 in., and the thick seams exceed 180 in. This additional detail is specified because seam thickness will surely be an important variable in the design of new equipment. Seam thickness stops at 28 in. since below that height manned operations seem to be impractical. The 42 in. height was selected because at about that height or below, a worker cannot easily move about on his feet. A seam height of 180 in. is currently near the upper limit of single pass longwall technology.

The multiple seam coals deserve a bit more discussion. As indicated in Section II (and more fully explained by Ferm and Muthig, 1982), multiple seams are a geologically significant resource which is inextricably confounded with conventional coals. In effect, mining seams one at a time versus mining seams with explicit provision for (simultaneous or) subsequent recovery of adjacent coals represent two different perspectives on the same resource base. Although present in significant amounts in all six provinces, multiple seams are mined today mostly in Appalachia, with a few operations in the Interior and the Rocky Mountains. Moreover, according to a recent study by Engineers International, Inc. (1980), the cost of coal from multiple seam mines average about 10% more than the cost of mining a seam "in isolation"*. In view of the abundance of multiple seams and the cost of recovery relative to "isolated seams", it is clear that the savings associated with improved technology for these resources would be comparable to (and possibly greater than) advanced technology for conventional (one-at-a-time) coals. Consequently, no separate savings calculations are made for multiple seam resources because such calculations are simply not necessary for the objectives of this study. Thus, in considering the analytical results obtained in Sections VII and VIII, the reader should bear in mind that savings associated with multiple seams are very likely to be of the same order of magnitude as savings estimated for conventional coals.

The analysis will now proceed on the coals listed in Category I. Note that the coals in Category I are singled out for detailed analysis because they are believed to be coals which are most likely to generate the largest savings. Coals in Categories II and III may be expected to produce substantially lower savings and will not be examined further in this study.

*As noted above, "insolation" is typically a state of mind, not a state of nature.

SECTION VII

COMPUTATION OF COST SAVINGS

A. INTRODUCTION

In this section the results of the savings calculations are presented and discussed. The section is divided into two parts. In the first part, the savings for the coals surviving the initial screening are given, together with the amount of BTUs delivered to the market. The second part of the section is devoted to detailed discussions of the cost savings.

The actual reporting of the savings takes two different forms. If the resource was originally included in EEA's analysis, the minimum mine-mouth price (MASP) at which the resource would be mined is known. Thus, it is meaningful to talk about reduction in price. If the resource was not included in EEA's analysis (North Alaska, for example) the price which would induce the coal to be exploited is not known, hence it is not meaningful to discuss the decrease in price. In this case, savings will be calculated and reported on the basis of the MASP needed to compete. In theory, one could put the savings of the coals in EEA's analysis in terms of MASP rather than change in price. However, because of differences in labor productivity assumed by EEA, the same coal could have the different mine-mouth prices even in the same supply region. Thus, "the price" of a certain type of coal in a given supply region is not unambiguously defined. Note that to talk about the savings due to a reduction in MASP, by say 50 mills, it is assumed that the MASP for the candidate coal drops by the same amount in all locations--50 mills in this case. Since the goal of this analysis is to discover which coals should be targets for an advanced coal mining system, and the main criterion is expected savings, it does not matter whether the savings are reported in terms of MASP or change in MASP.

Although estimates of savings are necessary to complete the targeting process, they are not sufficient. Additional information is required about the possibility of reducing the cost of mining a certain type of coal by a specified amount. By combining these judgments about likely technological advances with previous estimates of savings, additional targeting information can be developed. Thus, the savings and BTU schedules shown here do not by themselves tell the whole story. The analysis will, however, suffice to determine which, if any, of the coals should be removed from further consideration.

Before presenting the savings estimates, the meaning and use of these numbers will be discussed. Estimates of expected savings will be one of the main considerations in the targeting process. The fundamental probabilistic results are based on estimates of savings as a function of MASP. Although desirable, it is not necessary that the savings calculated here be accurate estimates of the actual savings that will occur. In fact, for reasons discussed in a moment, they probably will not be accurate. What is important is that the savings correctly rank the various coal types, since it is only a ranking of the coals that is needed for the final targeting. Finally, note that if more than one of the candidate coals were to be targeted, the savings of each coal could not simply be added together to obtain the total savings because the savings for each coal type were calculated by assuming that no other coal price changed.

Now that the use of the saving estimates is clear, the meaning of the numbers can be discussed. The numbers are reported in terms of $/year, and they represent the amount that would be saved circa 2000 if every mine where the new technology could be applied were opened and came into full production, capturing the competitor markets as the MASP fell. Note that the argument assumes that as the MASP falls, the new coal captures an entire market as soon as the new coal is 1 mill/MMBTU cheaper than the coal sold in that market without the benefit of radically new mining technology. Thus the savings are those which would accrue to those mines both in production and coming into production under the above conditions, and would continue over the life of the mines. In the calculation of savings, mines opened in 1985 in the EEA analysis were removed from consideration since these mines would be nearly depleted and probably not targets for advanced systems. Through an analysis of different demand scenarios in the year 2000, the sensitivity of the savings to alternative demands can be considered. Note that the savings are calculated on an annual basis so that demand growth and depletion in the years after 2000 are not explicitly considered. On the other hand, as long as the resource to which the new technology is applied is not severely depleted, savings would likely continue over the life of the resource.

B. OVERVIEW OF SAVINGS

This section presents savings estimates which have been generated using the data and methods outlined above. Both the savings and the BTUS required to realize these savings are given. The savings and the BTU's are, of course, closely related. These figures are more thoroughly discussed in part C of Section VII, where breakdowns by sulfur type are also given.

Tables 7-1 and 7-2 present the savings under the medium demand scenario for seams which are flat-lying, of moderate thickness, and under moderate cover. Similar tables for the low and high demand scenarios are given in Appendix B. Flat-lying means a pitch of 15^{o} or less; moderate cover means overburden of 500 - 2000 ft; and moderate thickness means a seam height of 28 - 180 in. In the calculations reported below, seam thickness is broken into two subcases: thin seams of 28 - 42 in., and medium thick seams of 42 - 180 in. The other variable of interest is the method of entry; here, both drift and shaft access are considered.

Table 7-1 reveals that both the method of entry and seam thickness are significant. Shaft entry does not provide levels of savings comparable to drift entry for comparable decreases in mine-mouth price. However, if a decrease in MASP of 300 mills/MMBTU or more can be achieved, the medium thick shaft mine type becomes competitive with thin drift coal. Tables B-1, B-2, B-15, and B-16 of Appendix B give the results for the high and low demand scenarios. In all three cases the rankings are the same: (1) medium thick drift; (2) thin drift; (3) medium thick shaft, and (4) thin shaft. In fact, the thin shaft coal does not provide savings comparable to the other conventional coals <u>at any MASP</u>.

In Table 7-3, savings are given for thick coals over 180 in. under the medium demand scenario. Similar tables for low and high demand scenarios are provided in Tables B-3 and B-17 of Appendix B. Because thick coals were not comprehensively studied by EEA, the MASP data for this resource is incomplete. Thus, as indicated in the discussion of study methodology, the savings for

Table 7-1. Conventional Seams: Savings under the Medium Demand Scenario (Millions of 1979 Dollars/Year)

If MASP Falls By Mills/MMBTU	Coal Types			
	Thin Drift	Thin Shaft	Medium Thick Drift	Medium Thick Shaft
50	304	4	502	137
100	543	5	920	271
150	867	6	1356	460
200	1190	8	1795	907
250	1550	21	2247	1141
300	1895	36	2712	1466
350	2242	51	3196	1802
400	2592	73	3897	2151

Table 7-2. Conventional Seams: Energy Content Replaced by Advanced Mining Technology under the Medium Demand Scenario (Quads/Year)

If MASP Falls By Mills/MMBTU	Coal Types			
	Thin Drift	Thin Shaft	Medium Thick Drift	Medium Thick Shaft
50	4.517	0.024	8.155	2.358
100	4.917	0.024	8.644	2.714
150	5.492	0.024	8.734	3.884
200	6.229	0.096	8.776	4.777
250	6.878	0.293	9.114	5.824
300	6.903	0.293	9.398	6.367
350	6.975	0.299	9.808	6.673
400	7.065	0.590	12.912	6.832

this resource are calculated as a function of mine-mouth MASP, rather than a decrease of mine-mouth MASP as is done for conventional coals. The striking aspect of Table 7-3 is the fact that advanced coal extraction technology would provide the thick coals with rather slim market opportunities.

C. ANALYSIS OF THE COST SAVINGS RESULTS

In this section, the savings generated by each of the candidate coals will be examined more closely. The idea is to see the typical price at which the conventional coals are being mined, and the alteration in coal flows which would occur if a new technology were available. Further, the source of savings by sulfur category will be examined. The conventional coals will be considered first, followed by the thick coals.

Table 7-3. Thick Coals: Savings and Energy Replacement under the Medium Demand Scenario

MASP Mills/MMBTU	SAVINGS (Millions of 1979 $/Year)	ENERGY REPLACEMENT (Quads/Year)
1450	0	0
1400	0	0
1350	0	0
1300	20	0.728
1250	57	0.728
1200	94	0.728
1150	130	0.728
1100	187	1.270
1050	267	2.025
1000	484	5.605
950	790	7.309
900	1155	7.309
850	1421	7.344
800	1956	9.639

1. Conventional Coals

Tables 7-4 through 7-11 show the savings per year and the BTUs by sulfur type for each of the four conventional coals, under the medium demand scenario. Tables B-4 through B-11, and B-18 through B-25 of Appendix B present corresponding results for the low and high demand scenarios.

To calculate the savings and BTU's the following factors were considered. First the supplies of the candidate coals were located geographically. Second, a determination was made of the mine-mouth price at which these coals could compete with other coals both inside and outside the supply region. With these prices as guides, the candidate coals were assumed to flow to the appropriate demand region as they became competitive, supplanting all coal above the competitive price until the supply of coal was exhausted, or all the demand was filled.

A candidate coal can replace another coal in a given demand region if the candidate coal has a lower price than the other coal in that demand region, or if the other coal is depleted. A candidate coal can fail to compete if its price is too high to be competitive.

Specific candidate coals will now be discussed, starting with the conventional coals. The most striking fact is that the two shaft coals (thin and medium thick) fail to be competitive in the compliance market. In terms of savings, the two drift coals dominate all three sulfur categories, with one exception. For reductions in MASP greater than 200 mills/MMBTU, the savings associated with low sulfur coal are greater for medium shaft coal than for thin drift coal. Thus, the thin shaft coals can be dropped from further analysis since they are exploited in such small amounts, and exhibit lower savings than all other conventional coals (see Figure 7-1).

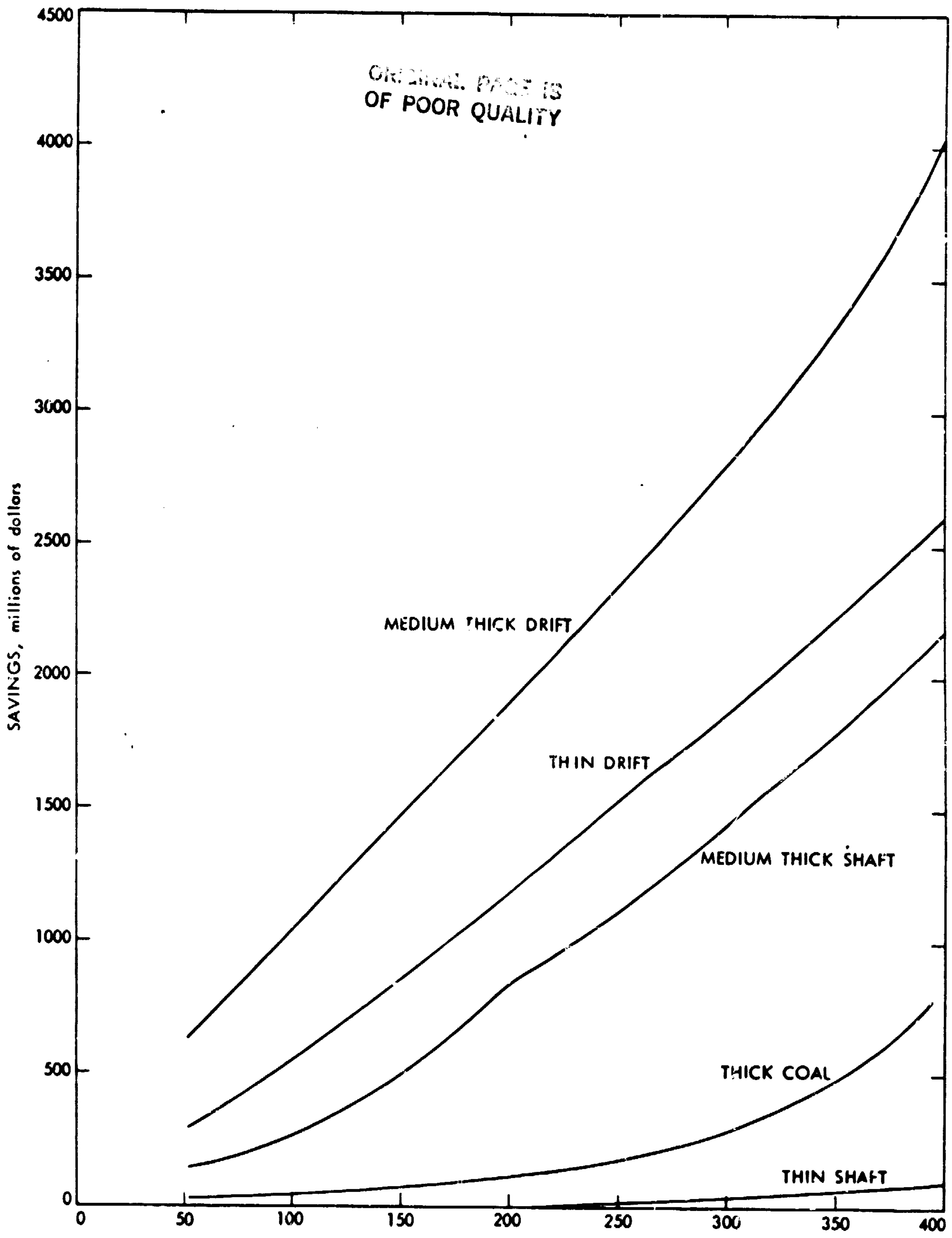

Figure 7-1. Savings in 1979 Dollars for Candidate Coals Under the Medium Demand Scenario

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Table 7-4. Thin Drift Coals: Savings under the Medium Demand Scenario (Millions of 1979 Dollars/Year)

If MASP Falls Mills/MMBTU	Sulfur			TOTAL SAVINGS
	Compliance	Low	High	
50	37	133	135	305
100	73	266	203	542
150	110	400	357	867
200	146	535	509	1190
250	183	672	695	1550
300	220	810	865	1895
350	256	949	1037	2242
400	293	1087	1212	2592

Table 7-5. Thin Drift Coals: Energy Replacement under the Medium Demand Scenario (Quads/Year)

If MASP Falls Mills/MMBTU	Sulfur			TOTAL QUANTITY
	Compliance	Low	High	
50	0.732	2.607	1.177	4.517
100	0.732	2.680	1.505	4.917
150	0.732	2.680	2.080	5.492
200	0.732	2.688	2.808	6.228
250	0.732	2.761	3.334	6.877
300	0.732	2.761	3.409	6.902
350	0.732	2.770	3.474	6.976
400	0.732	2.770	3.563	7.065

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Table 7-6. Thin Shaft Coals: Savings under the Medium Demand Scenario
(Millions of 1979 Dollars/Year)

If MASP Falls Mills/MMBTU	Sulfur			TOTAL SAVINGS
	Compliance	Low	High	
50	0	4	0	4
100	0	5	0	5
150	0	6	0	6
200	0	7	1	8
250	0	9	12	21
300	0	11	25	36
350	0.03	12	38	40.03
400	0.42	14	59	73.42

Table 7-7. Thin Shaft Coals: Energy Replacement
under the Medium Demand Scenario
(Quads/Year)

If MASP Falls Mills/MMBTU	Sulfur			TOTAL QUANTITY
	Compliance	Low	High	
50	0	0.024	0	0.024
100	0	0.024	0	0.024
150	0	0.024	0	0.024
200	0	0.024	0.071	0.095
250	0	0.032	0.261	0.293
300	0	0.032	0.261	0.293
350	0.005	0.033	0.261	0.299
400	0.017	0.051	0.522	0.590

Table 7-8. Medium Thick Drift Coals: Savings under the Medium Demand Scenario (Millions of 1979 Dollars/Year)

If MASP Falls Mills/MMBTU	Sulfur			TOTAL SAVINGS
	Compliance	Low	High	
50	49	168	285	502
100	98	342	480	920
150	150	528	678	1356
200	205	715	875	1795
250	269	902	1076	2247
300	343	1088	1280	2711
350	424	1275	1497	3196
400	592	1593	1711	3896

Table 7-9. Medium Thick Drift Coals: Energy Replacement under the Medium Demand Scenario (Quads/Year)

If MASP Falls Mills/MMBTU	Sulfur			TOTAL QUANTITY
	Compliance	Low	High	
50	0.976	3.377	3.802	8.155
100	0.976	3.718	3.949	8.643
150	1.050	3.733	3.951	8.734
200	1.091	3.733	3.953	8.777
250	1.328	3.733	4.059	9.143
300	1.584	3.733	4.082	9.399
350	1.738	3.791	4.279	9.808
400	2.652	5.955	4.305	12.912

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Table 7-10. Medium Thick Shaft Coals: Savings under the Medium Demand Scenario (Millions of 1979 Dollars/Year)

If MASP Falls Mills/MMBTU	Sulfur			TOTAL SAVINGS
	Compliance	Low	High	
50	0	131	6	137
100	0	247	24	271
150	0	385	75	460
200	0	536	371	907
250	0	681	460	1141
300	0	854	612	1466
350	0	1028	774	1802
400	0	1219	932	2151

Table 7-11. Medium Thick Shaft Coals: Energy Replacement under the Medium Demand Scenario (Quads/Year)

If MASP Falls Mills/MMBTU	Sulfur			TOTAL QUANTITY
	Compliance	Low	High	
50	0	2.174	0.184	2.358
100	0	2.334	0.381	2.715
150	0	2.510	1.375	3.885
200	0	2.811	1.966	4.777
250	0	3.351	2.473	5.824
300	0	3.465	2.903	6.368
350	0	3.525	3.149	6.674
400	0	3.674	3.159	6.833

Several noteworthy alterations in coal flows occur as the mine-mouth prices change. Table 7-12 summarizes these changes in flows; the MASP at which the changes become effective is shown in parentheses. Several things should be noted. First, the alteration in coal flows take place at relatively high MASPs; thus, some are likely to occur even if the mine-mouth price has not been lowered significantly. Second, total replacement of one coal by another does not usually happen because the MASP is not allowed to drop far enough in this analysis. Finally, note that the main gainer in this analysis is supply region 5--the Illinois Basin. In the medium scenario the largest gains accrue to the Illinois Basin (5), with most of the gains occuring in high sulfur coal. Oklahoma-Arkansas (7), Ohio (1) and Northern Appalachia (2) also gain in high sulfur. The gainers for compliance coal are the central and southern Appalachian regions (3, 4) as well as two western regions (13 and 14). For low sulfur coal, the main gains go to region 5. The areas hardest hit by the change in technology are the Appalachian regions (2, 3, 4) and Central Midwest (6). Again the greatest impact will be felt by the high sulfur coals. In the case of low sulfur coal, Appalachia (3 and 4) bears the greatest portion of the cost. As Appendix B indicates, the pattern of alteration of coal flows depends on the demand scenario assumed.

The basic reason for the large shifts in the flow of high sulfur coal is that the high sulfur coals located in the Illinois Basin are strongly competitive with the high sulfur coals in other regions. Thus, small reductions in MASP allow Illinois coal to replace other high sulfur coals.

2. Thick Seams

The very thick coals are an interesting resource found largely in the western U.S. Thick coals are defined as all seams over 15 ft thick. The best current method for mining thick coal is a multiple pass system wherein successive slices are taken by a longwall system, commercing at the top of the seam and working downward. Tables 7-13 and 7-14 indicate that the savings projected for thick coals are not large, principally because they are located in close proximity to strippable resources. A separate analysis was done for coals over 50 ft thick; however, the savings are so low they are not worth reporting. Based on savings calculations, it is unlikely that the thick seams will be a viable target for advanced underground mining systems.

In order to compare these results for thick seams with the savings for conventional coals, it is necessary to recast them in terms of a change in MASP, defined as the reduction in MASP from the forecast regional equilibrium price. This was done by determining the MASP at which savings were likely to begin accruing and then using this MASP as the origin for the transformation to a change in MASP. The value of the origin for MASP was selected by examining all supply regions containing substantial amounts of thick, flat-lying coal and noting the maximum surface mining cost circa 2000. The largest of these regional stripping costs was selected as the origin, yielding a value of 1335 Mills/MMBTU (in 1979 dollars). Results of the transformation to a MASP format are plotted in Figure 7-1, which indicates clear dominance of medium thick and thin drift coals. Since it is rather unlikely that any underground method will ever be competitive with surface mining techniques, the comparison of Figure 7-1 amounts to an a fortiori result: an assumption was made (MASP at which savings begin) which strengthened the case for thick coals substantially beyond what is expected to occur; yet in spite of this attempt to tip

Table 7-12. Alteration of Coal Flow Due to New Technology under the Medium Demand Scenario
(MASP at Which Flows Change in Mills/MMBTU)

COAL TYPE	THIN DRIFT			THIN SHAFT			THICK DRIFT			THICK SHAFT		
SULFUR TYPE	Supply Region	To Demand Region	To Replace Supply Region	Supply Region	To Demand Region	To Replace Supply Region	Supply Region	To Demand Region	To Replace Supply Region	Supply Region	To Demand Region	To Replace Supply Region
Compliance	NONE	NONE	NONE	3(1288)	12	13	3(1288)	12	13	NONE	NONE	NONE
				4(1742)	7	3	13(1033)	14	15			
				14(1033)	14	15						
Low	7(1069)	4	3	1(1586)	4	3	3(1433)	6	4	5(1025)	5	3
				3(1281)	6	4				5(1197)	6	3
										5(1045)	6	[illegible]
										5(1035)	7	4
										5(1128)	9	4
										5(1064)	11	12
High	1(879)	7	4	1(934)	3	2	2(1131)	6	4	1(803)	1	2
	2(9[illegible]6)	5	3	1(892)	7	5	5(717)	7	4	1(799)	2	2
	2(1021)	6	3	1(829)	7	4	5(787)	7	7	1(934)	3	2
	2(965)	6	4	1(835)	6	3	5(1043)	12	6	5(717)	7	4
	5(592)	10	6	1(843)	6	4	5(592)	10	6	5(1043)	12	6
	5(1043)	12	6	5(1043)	12	6	7(1001)	11	6	5(787)	7	7
	5(989)	12	5				7(958)	8	8	5(592)	10	6
										5(875)	6	4
										5(851)	6	3
										5(685)	8	8
										7(582)	11	4
										7(1001)	11	6

Table 7-13. Thick Coal: Savings under the Medium Demand Scenario (Millions of 1979 Dollars/Year)

MASP Mills/MMBTU	Sulfur			TOTAL SAVINGS
	Compliance	Low	High	
1450	0	0	0	0
1400	0	0	0	0
1350	0	0	0	0
1300	0	0	20	20
1250	0	0	57	57
1200	0	0	94	94
1150	0	0	130	130
1100	21	0	166	187
1050	63	1	202	266
1000	171	74	239	484
950	303	211	275	789
900	436	407	312	1155
850	569	604	248	1421
800	702	800	454	1956

Table 7-14. Thick Coal: Energy Replacement under the Medium Demand Scenario (Quads/Year)

MASP Mills/MMBTU	Sulfur			TOTAL QUANTITY
	Compliance	Low	High	
1450	0	0	0	0
1400	0	0	0	0
1350	0	0	0	0
1300	0	0	0.728	0.728
1250	0	0	0.728	0.728
1200	0	0	0.728	0.728
1150	0	0	0.728	0.728
1100	0.542	0	0.728	1.270
1050	1.239	0.058	0.728	2.025
1000	2.654	2.223	0.728	5.605
950	2.654	3.927	0.728	7.309
900	2.654	3.927	0.728	7.309
850	2.654	3.927	0.764	7.345
800	2.654	3.927	3.076	9.657

the balance in favor of thick coals, they are clearly dominated by certain classes of conventional resources (and most probably, multiple seams). Therefore, one can only conclude that on the basis of deterministic savings projections, thick coals are a relatively unattractive resource target. In Section VII, this conclusion will be tested by considering the likelihood of actually achieving specified levels of MASP reduction via the introduction of advanced mining technology for this resource.

D. SUMMARY

All Category I coals have been examined to project the amount of savings which can be generated by each resource type. The outcome of this analysis suggests that further attention should be paid to the likelihood that reductions in MASP can be achieved. In the absence of such information about plausible technological advances, the leading contenders are the drift entry conventional coals, the multiple seams, and the medium thick shaft coals (depending on reduction in MASP). The thin-shaft and thick coals seem least attractive at this juncture. As explained above in Section VI, multiple seams were not analyzed separately because they are confounded with conventional coals, are abundant in all provinces, and exhibit a mining cost somewhat above seams mined one-at-a-time--all of which implies that a priori, multiple seams are a resource target only somewhat less attractive than conventional coals. Additional information will be brought to bear on the relative attractiveness of these resources via a probabilistic analysis of savings, reported in Section VIII.

SECTION VIII

LIKELIHOOD OF ACHIEVING COST SAVINGS

In this section the calculation of expected savings is discussed. This calculation combines the savings obtained in the last section with probabilistic judgments about the likelihood of achieving the reduction in MASP necessary to realize those savings.

A. PROBABILITY OF A REDUCTION IN SELLING PRICE

The deterministic savings associated with the various candidate coals have been reported in Section VII and are used here in a final analysis. By themselves these savings estimates do not tell the whole story regarding expected savings. Suppose that large savings are indicated for a certain coal, provided that the MASP falls to low enough levels. The problem is to know whether that decrease in MASP can reasonably be expected to occur. The determination of this likelihood is difficult because both the technology to be used and the amount of funding available for its development have not been specified. The following rule for ordering the savings seems likely to hold and will be used in the analysis of this section: greater reductions in MASP are less likely than small reductions in MASP. Clearly the magnitude of these probabilities also depend on the amount of research and development that occurs, which in turn depends on the amount of money spent on research and development.

The probability of achieving a particular MASP or reduction in MASP is described in terms of a probability density function. A truncated geometric function was selected because it is a simple function which obeys the ordering rule adopted above, namely, that larger MASP reductions (lower MASP values) become increasingly less likely. More specifically, the probability density function is defined as

$$f(x) = \frac{P(1-P)^x}{1-(1-P)^{N+1}} \qquad x = 0, 1, \ldots, N.$$

The assumption of any particular probability density function is strong, and any other choice would probably change the expected savings. However, if the same probability distribution for MASP reduction is used for all coal types, the ordering of the expected savings should not change drastically because the savings for each coal type increases monotonically as the MASP drops. In particular, if the probability weights are rearranged, thereby increasing the weight on lesser or greater changes in MASP, the order in which the expected savings are ranked should not change dramatically. This argument should be reexamined in the case where there are zero savings for some MASPs. In such a case, altering probabilities may well affect the ranking.

B. UPPER AND LOWER BOUNDS ON PRICE

The distribution given here depends on two parameters, P and N. The parameter P is the probability that the first 50 mill decrease in MASP will be achieved by the new technology. The parameter N is the number of 50 Mill/MMBTU decreases in MASP. To obtain values for N, an upper bound MASP and lower bound MASP were estimated, and the difference between those MASPs was translated into the number of 50 mill increments, N. The upper bound MASP was taken to be the minemouth price in 2000 using the technology applicable to a specific coal type. Alternate values of P can be used if it seems unlikely that the upper bound prices are not as likely (or more likely) than the P assumed. The lower bound MASP is essentially a MASP below which the new technology would be very unlikely to deliver coal.

As indicated by the preceding discussion, the choice of P and N is open to question. Thus, the analysis which follows examines the sensitivity of expected savings (and hence, the relative ranking of coal types) to the assumed values for P and N. The next task is the determination of the upper and lower limit over which the MASP will range. For resources included in EEA's analysis, the expected MASP of those coals in production in 2000 is known. Thus, if no change in technology occurs, it is presumed that these coals can be extracted at EEA's year 2000 MASP. A weighted average of such numbers will provide an upper bound. On the other end of the scale, it may reasonably be expected that these coals cannot be mined more cheaply than their strippable counterparts; an average of these numbers provides a lower bound. Thus, an upper price and lower price for each mine type can be determined in a straightforward manner. Note that there is no a priori reason why the research and development will produce new technology to mine coal at these prices. However, it is believed that the preponderance of probable outcomes will lie largely within this range. Observe that the range determined above may yield MASPs for which no savings accrue. Just because conventional technology could mine coal for a certain MASP does not mean that there will be a market for that coal at that MASP. This is the case for some resources not included in EEA's analysis.

Because thick coals were not comprehensively studied by EEA, the estimation of an upper and lower price is more difficult since there is little data on which to base the choice. A lower price can be obtained from strip mining practice as before. The upper price for thick coals can be estimated as follows. As indicated previously, thick coals are currently mined by a multiple slice longwall technique. Contemporary longwall supports permit mining coals up to 15 ft thick, and this technology appears extendable to a 20 ft. seam height. Since the analysis of U.S. coal resources by Ferm and Muthig (1982) revealed very few seams over 50 ft thick, and since present practice is to leave some coal between slices, it appears that a two-slice approach would suffice to mine most of the thick U.S. coals today (c.f. the discussion in Section II.B above). Conversations with those familiar with the multiple slicing technique indicated that the first slice is negligibly more expensive and the second slice--perhaps 25% more costly than conventional longwall operations. Thus, the upper bound for thick coals will be taken to be 1.12 times the cost of mining a 15 ft seam by contemporary longwall techniques. To add an additional contingency, shaft entry was assumed.

Table 8-1 presents the upper and lower bound prices for the various coals in the low, medium and high demand scenarios. As indicated in the above discussion, MASPs from EEA's forecast of coals in production in the year 2000 were an important imput to these bounds. The upper and lower MASPs for conventional seams were obtained by taking the average MASP for underground coals (by mine type) expected to be in production in the year 2000 (upper bound) and

Table 8-1. Upper and Lower Bounds Used for the MASP in 1979 Dollars (Mills/MMBTU)

Coal Type	Low Demand Scenario		Medium Demand Scenario		High Demand Scenario	
	Upper	Lower	Upper	Lower	Upper	Lower
Thin Drift	1075	860	1070	860	1070	860
Thin Shaft	1210	860	1210	860	1210	860
Medium Thick Drift	1115	815	1120	815	1155	815
Medium Thick Shaft	1175	815	1215	815	1290	815
Thick Seams	1315	630	1360	630	1445	630

the average MASP for surface coals expected to be in production in the year 2000 (lower bound). The strip coals are categorized by seam thicknesses and not entry method. Thus, the thin strip coals are matched to the thin drift and thin shaft mines. The lower bound for the thick coals is also obtained by averaging MASP for similar surface coals. The upper bound for thick seams was obtained by multiplying the MASP of the thick shaft coals by 1.12 as explained above. These estimates are crude and since the final results depend on those choices, the sensitivity of the results to these assumptions will be examined later in this section.

Some anomalies appear in Table 8-1. It seems reasonable that thin seams should be more expensive to mine than thick seams, all else being equal. This is confirmed in the data for the strip mines, but it does not seem to be true for the underground mines. The problem is that not all else is equal. In particular, the less expensive, thicker underground mines were opened earlier than the more expensive, thin seam mines, and the thicker coals are now depleted. Thus, the current mine-mouth costs are very nearly the same for those two underground coals. One other interesting phenomenon is revealed in Table 8-1. The upper price for thin drift mines falls in going from the low to the high demand scenario. Apparently, in the high scenario, many lower cost mines are being opened in less accessible areas. Thus, the average mine-mouth price falls, but the delivered price of coal rises.

C. EXPECTED SAVINGS FOR EACH DEMAND SCENARIO

Tables 8-2 through 8-5 summarize the savings calculations for all coals subject to a probabilistic analysis. Note that data for all three demand scenarios are tabulated because it was felt that scenario content could have significant impact upon the ranking of coal types.

The expected savings can now be calculated given the savings, and a probability density with parameters P = 0.75 and the N dictated by the upper bound and lower bound prices. The results of the expected calculations are shown in Table 8-6. Since the value of P was chosen somewhat arbitrarily, a sensitivity analysis was done on this parameter with results reported in Section VIII.D.

Table 8-2. Conventional Coals: Summary of Deterministic Savings under the Low Demand Scenario (Millions of 1979 Dollars/Year)

If MASP Falls By Mills/MMBTU	Coal Types			
	Thin Drift	Thin Shaft	Medium Thick Drift	Medium Thick Shaft
50	135	1	133	80
100	257	2	276	163
150	453	3	430	272
200	608	4	605	511
250	776	5	805	662
300	946	7	1030	838
350	1119	21	1270	1056
400	1292	35	1600	1287

Table 8-3. Conventional Coals: Summary of Deterministic Savings under the Medium Demand Scenario (Millions of 1979 Dollars/Year)

If MASP Falls By Mills/MMBTU	Coal Types			
	Thin Drift	Thin Shaft	Medium Thick Drift	Medium Thick Shaft
50	304	4	502	137
100	543	5	920	271
150	867	6	1356	460
200	119[illegible]	8	1795	907
250	1550	21	2247	1141
300	1895	36	2712	1466
350	2242	51	3196	1802
400	2592	73	3897	2151

Table 8-4. Conventional Coals: Summary of Deterministic Savings under the High Demand Scenario (Millions of 1979 Dollars/Year)

If MASP Falls By Mills/MMBTU	Coal Types			
	Thin Drift	Thin Shaft	Medium Thick Drift	Medium Thick Shaft
50	626	41	670	409
100	913	81	1166	617
150	1272	129	1678	1008
200	1656	181	2192	1423
250	2051	242	2688	1867
300	2409	309	3371	2298
350	2874	381	3980	2757
400	3337	515	4837	3233

Table 8-5. Thick Coals: Deterministic Savings under the Three Demand Scenarios (Millions of 1979 Dollars/Year)

Mills/ MMBTU	Low Demand	Medium Demand	High Demand
1800	0	0	0
1750	0	0	0
1700	0	0	0
1650	0	0	0
1600	0	0	0
1550	0	0	0
1500	0	0	0
1450	0	0	0
1400	0	0	0
1350	0	0	0
1300	0	20	41
1250	0	57	114
1200	0	94	186
1150	0	130	259
1100	0	187	411
1050	0	267	606
1000	89	484	971
950	254	790	1429
900	478	1155	1946
850	702	1421	2464
800	995	1956	3044

Table 8-6. Expected Savings for P = 0.75
(Millions of 1979 Dollars/Year)

Scenario	Thin Drift	Thin Shaft	Medium Thick Drift	Medium Thick Shaft	Thick Seams
Low	181	1	182	112	0.04
Medium	390	4	643	191	8
High	726	55	1204	494	1

Table 8-6 indicates that the coals fall roughly into two groups. The thin drift seams, the medium thick shaft and the medium thick drift seams all have savings that are closely comparable. The second group consists of the thin shaft seams, and the thick coals, with significantly less savings than the other coals. The substantially lower expected savings projected for thick seams in Table 8-6 results from the upper bound on price being considerably above the price where savings start; i.e., substantial probability weighting is applied to prices where the savings are zero. In particular, the upper bound for thick coals is about 1350 Mills/MMBTU while the savings start at 1000 Mills/MMBTU. Finally, note that the ranking of the two groups of coals is insensitive to the choice of demand scenario.

Several sensitivity analyses were done in order to explore the relationship between the expected savings and the shape of the underlying probability distribution. Recall that the parameter P is the probability of achieving the first reduction in MASP. Note that as P gets smaller, the distribution gets flatter. Thus, expected savings will rise as P falls since the savings increase with falling MASP. Table 8-9 presents expected savings for P = 0.5.

D. SENSITIVITY OF EXPECTED SAVINGS TO DISTRIBUTION PARAMETERS

As indicated by Tables 8-7 and 8-8, the reduction in P from 0.75 to 0.50 causes thick coals to become somewhat more attractive targets because the upper bound is closer to the MASP where savings begin. However, only under the low demand scenario did thick seams move up in the ranking. If P were reduced further, thick coals would exhibit greater expected savings; however, it appears that a substantial reduction in P would have to occur before thick coals became as attractive as the medium and the thin drift seams.

A second sensitivity analysis was done on the parameter N. There was no a priori way to tell which way expected savings would change as N changed. In general, N was expected to have a small impact on expected savings because of the functional form of f(x). In each case, N was increased by 1. Results are shown in Table 8-9. Note that small changes in N have only superficial impacts on the savings and no changes in the ranking. Of course, larger changes in N may have some impacts, but the upper and lower bounds on MASP effectively limit these changes.

Table 8-7. The Impact of a Change In P on Expected Savings: P = 0.5
(Millions of 1979 Dollars/Year)

Scenario	Thin Drift	Thin Shaft	Medium Thick Drift	Medium Thick Shaft	Thick Seams
Low	270	2	281	197	4
Medium	557	6	919	337	33
High	920	86	1332	716	17

Table 8-8. Expected Savings as a Function of Demand Scenario and Probability of Achieving the First 50 Mill Reduction in MASP (P)
(Millions of 1979 Dollars/Year)

Resource Type	P = 0.75			P = 0.50		
	Demand Scenario			Demand Scenario		
	Low	Med	High	Low	Med	High
Medium Thick Drift	182	643	1204	281	919	1332
Thin Drift	181	390	726	270	557	920
Medium Thick Shaft	112	191	494	197	337	716
Thick Seams	0.04	8	1	5	33	17
Thin Shaft	1	4	55	2	6	86

Table 8-9. The Impact on Expected Savings of a Unit Increase in N for P = 0.75
(Millions of 1979 Dollars/Year)
Note: The Original N is Shown in Parenthesis

Scenario	Thin Drift	Thin Shaft	Medium Thick Drift	Medium Thick Shaft	Thick Seams
Low	181	1	182	112	0.04
	(5)	(7)	(6)	(8)	(14)
Medium	391	4	643	191	8
	(5)	(7)	(7)	(8)	(14)
High	728	55	962	494	1
	(5)	(7)	(7)	(10)	(17)

A second perspective on the sensitivity of the resource rankings to the likelihood of MASP reductions is obtained by determining values for the distribution parameters which yield identical expected savings for all resource types. More specifically, one chooses a value for savings, fixes N, and then solves for the value of P that produces the indicated level of savings. To intepret the results, one must take a closer look at the distribution. Note that as P gets smaller, the distribution gets flatter. That means that a coal with savings requiring a large decrease in MASP will need a flatter distribution to achieve the expected savings. As indicated above, a smaller P will be required to bring these candidates into a competitive position. Accordingly, an alternative way to view this is that if a coal requires large decreases in MASP to achieve a given level of expected savings, the mean of the probability density must be low. Therefore, a determination of the mean reduction in MASP will produce a ranking of resource types that is equivalent to the solution for P of fixed savings and N, as outlined above. The mean of a truncated geometric density function can be written as follows:

$$\mu = \frac{(1-P) - (PN+1)(1-P)^{N+1}}{P - P(1-P)^{N+1}}$$

Table 8-10 presents the mean reduction in MASP (expressed in Mills/MMBTU) for levels of savings roughly representative of the values listed in Table 8-7. Results are shown for all three demand scenarios. Examination of Table 8-10 reveals some changes from the previous analysis. First, the drift and medium shaft conventional coals remain top ranked, however, in the low demand scenario the thin drift coals are ranked number one over the medium drift resource type. This is counterintuitive and may be an artifact of the particular values chosen for this calculation. Second, thick seams now dominate the thin coals for all three demand scenarios, with thick coals not being very different from medium shaft resources in the low demand case.

E. SUMMARY

In summary, the analysis of Section VIII has revealed a rather stable ranking of resource types under rather severe tests of the robustness of the numerical values used to characterize the judgments about possible reductions in MASP. In particular, for the restricted set of resources analyzed, it is clear that

- conventional coals with drift access are top ranked;
- medium height conventional seams with shaft access are almost as attractive as the drift access conventional coals; and
- thick coals and thin seams occupy bottom positions in the ranking, with thick seams exhibiting somewhat bigger expected savings, especially for the two higher demand scenarios.

Interestingly enough, this pattern is quite consistent with the results of the deterministic savings calculations made in Section VII (e.g., see Figure 7-1). Section IX integrates these numerical results with the preliminary screening of Section VI to produce a set of resource recommendations consistent with the targeting criteria in Section IV.

Table 8-10. Mean Reduction in MASP to Achieve a Specified Level of Expected Savings, as a Function of Demand Scenario (Mills/MMBTU)

Specified Savings:	Demand Scenario Low 0.5 Billion	Medium 1 Billion	High 1 Billion
Resource Type:			
o Medium Thick Drift	130	58	19
o Thin Drift	116	118	57
o Medium Thick Shaft	141	166	87
o Thick Seams	297	344	242
o Thin Shaft	___*	___*	___*

*The specified level of savings is too large to permit a solution; i.e., no solution for the mean is possible for positive values of x.

Before moving on to formulate targeting recommendations, two caveats are necessary. First, it must be emphasized that selection of resource targets depends on projections twenty years into the future. However, to deal with this problem, three demand scenarios were considered, and the results of the analysis were not much changed. Thus, this concern appears to be of lesser importance. A second and more important concern is with the shape of the probability density used to obtain the expected savings calculations. The shape of the function is crucial, because as the shape changes, the expected savings change, and the ranking may change. Although the relative ranking of the conventional coals is not likely to change very much, the ranking of the conventional coals vis a vis thick coals may change substantially. There is no a priori way to know which shape is correct. Again, some of this concern has been removed by examining the sensitivity of the targeting to changes in the parameters of distribution.

SECTION IX

RESOURCE TARGETS AND RESEARCH AND DEVELOPMENT STRATEGY

In this section, the targeting procedure is completed and the targeting recommendations are made. This section has two parts. In the first part, the expected savings are presented and the targeting objectives are reviewed. In the second part, the targeting objectives are applied to the coals, and final recommendations are made.

A. SUMMARY OF THE EVIDENCE

From Section VIII the candidate coals for advanced coal extraction systems were ranked as follows on the basis of expected savings:

(1) Medium Thick Drift
(2) Thin Drift
(3) Medium Thick Shaft
(4) Thick Seams, Multiple Seams
(5) Thin Shaft

If the only criterion were savings, the candidate coals to choose would be the ones ranked above. However, as discussed in Section IV, there are other secondary criteria, which are summarized below:

(1) To provide an advanced coal extraction system that would be financially attractive to the small miner.

(2) Minimize the required social and/or economic disruptions.

(3) Select resources so that a maximum amount of strip-mined coal production is replaced.

B. RECOMMENDATIONS

Both the deterministic and probabilistic analysis of savings indicate the clear dominance of so-called conventional coals (flat-lying seams of moderate thickness, under moderate cover, mined one at a time) over thick seams, except for thin shaft coals which may be as attractive as thick seams under either a very high or very low demand scenario. As indicated in the initial screening of resource types, these conventional coals are inextricably confounded with multiple seams, with the latter currently exhibiting a somewhat higher mining cost. The abundance of multiple seams (see Section II), together with their higher mining cost, implies a level of savings of the same order of magnitude but numerically less than the more attractive conventional coals. Within the category of conventional coals, seams which are accessible via drift entry are the more attractive, with medium thick seams (42 - 180 in.) having top ranking in all cases analyzed. As indicated in Section VIII, these findings are rather insensitive both to changes in the parameters of the probability density function used in the calculation of expected savings and to the assumed demand scenarios.

Now consider the secondary criteria. Note that if the small mining operation tends to seek out drift opportunities so that the "upfront" cost is reduced and the revenue stream will start sooner, the choice of either of the drift coals would be consistent with the first secondary objective.

Since the conventional coals are found in all regions, it is not clear that the regional impacts vary with the coal type selected for conventional coals. The main regional concern is whether the thick coals, which are found in the West, should be a target. The basic tradeoff is against savings. Since the thick coals generate relatively small expected savings and may cause regional dislocations, it is not clear why they should be a target coal. The point is that if the thick coal were chosen as a target coal rather than the the medium thick shaft coals, then the savings will be smaller by at least a factor of five, and some regional impacts will also be felt.

The third secondary criterion is the replacement of strip-mined coal by underground production. The basic argument here is that replacing strip mining is good; some environmental costs will be avoided if the role of strip mining is diminished as an energy source. Since the conventional coals and surface coals are available in all provinces, there is no reason to believe that one conventional coal would be relatively more successful in competing with the strip coals than another. The western thick coals, on the other hand, are likely to replace or compete largely with strip coals.

With the above discussion as background, the final recommendations can now be made. It is very likely that the optimal expenditure of funds on research and development requires funding of more than one project. The basic reason is that the level of "success" generated by the research and development effort is unknown and uncertain. One way to reduce the risk of failure is to allocate research and development money to a carefully chosen portfolio of projects. Although alterative strategies to manage risk are available, a common strategy is to choose projects with different levels of uncertainty. If that strategy is favored, the coals should be categorized by the likely risk of developing commercially attractive mining systems. In some sense this has already been done in the initial screening of Section VI, in which the coals were categorized by their likely savings. It is now appropriate to review that categorization to see what impacts the secondary targeting criteria would have.

The Category I coals have already been discussed. The Category II coals are the lignites, which are regional deposits, the varieties of thin coal (thin coals and coal with rock partings), and the deep coals. All these resources involve regional considerations. The thin coals, although found everywhere, are more prominent in the East and are more attractive R and D targets there because of depletion. The deep coals are found predominantly in the West. Thus, there is some regional interest in each of these coals, but the interest is generated largely in regions where mining currently occurs. Thus, disruption may be caused if these coals are not targets.

The other secondary criteria do not lend themselves to evaluation at this level. Note too, that technology does exist for mining the deep coals, so that further reductions in MASP due to changes in technology may be less likely than for coals with a less developed technology. The Category III coals also have a regional component. The abandoned pillars are found largely in the East. The steeply pitching seams are found in a variety of locations, but they are small in size. Again, some very effective technology has already been developed for mining steeply pitching coal.

In consequence, the only substantial change in the categorization is to remove the thick coals and multiple seams from Category I. There is no obvious reason to believe that these resources have expected savings greater than the Category II coals, and so these coals are shifted into Category II. No other change appears to be needed.

CATEGORY I	CATEGORY II	CATEGORY III
- Conventional Coals: Flat-lying seams of moderate thickness, under moderate cover	- Thick Seams - Multiple Seams - Thin Coals - Rock/Coal - Lignites - Deep Coals	- Alaskan Coals - Abandoned Pillars - Steep Coals

The targeting recommendations can now be summarized as:

(1) Some conventional coals should be chosen. These coals have the greatest economic potential and generally satisfy all criteria.

(2) Some Category II coals could be chosen. The coal to choose depends on factors not considered in this analysis. Almost every one of these coals could have important impacts on a given region, although the thin coals have national constituents.

(3) If some funds are available for research on more speculative projects, the Category III coals would come into consideration. Again, precisely which coal to choose depends on factors beyond the scope of this analysis.

APPENDIX A

ANALYSIS OF ALASKAN COALS AND GULF COAST LIGNITES

A. ALASKA

The Alaskan coals of primary interest are located in the Brooks range, contiguous to the oil fields currently being exploited on the North Slope. The Brooks Range coals are important for their sheer volume; they constitute about one-third of our national coal resources and are found in various geological structures similar to their counterparts in the Rocky Mountain Province.

There are some smaller basins further south, a few of which are currently being mined with surface methods. Moreover, expansion of surface mining activity in this area seems imminent. Accordingly, these coals will explicitly be accounted for in the analysis of the Brooks Range coals; however, as described by Ferm and Muthig (1982) these coals are not part of the set of candidate resources because of insufficient data to define their character and tonnage.

Note that the Alaskan coals are broken out not because their geology is fundamentally different (it is not), but because of their distance from markets, and because of the challenging mining conditions. The challenging conditions revolve around the temperature, temperature induced effects (permafrost), and environmental considerations. Note that an advanced system developed for general geological conditions which are also found in Alaska should be adaptable to the Alaskan resource. Thus, one source of savings (Alaska) may have been overlooked when the conventional coals were examined in the analysis reported in the text. For all these reasons, the Alaskan coals deserve a closer look.

What markets could the Alaskan coals possibly penetrate? The obvious answer is the Orient or Pacific Rim made up largely of Japan, Mainland China, Korea, and Tawain. The U.S. West Coast would also be a possibility. To assess whether the Alaskan coals can compete, the current suppliers of those markets must be identified.

Work done by ICF (1980) provides some information concerning supplies of coal from Australia, South Africa, and Western Canada. This information, together with information on ocean freight rates, permitted an estimate of the cost of delivering coal from the various resource locations to the demand points. Two demand scenarios were analyzed for the year 2000. A low scenario was obtained from the World Coal Study (Wilson, 1980). A high scenario was constructed by multiplying the low scenario demands by 1.67, thereby making this scenario consistent with the high demand scenario used in the text. The supplies were then allocated to the demands that approximately minimized the cost of delivered coal. The savings accruing to Alaskan coal could then be calculated as in the case of thick seams. Note that the southern Alaska coals were considered in these calculations.

The results in terms of savings are given in Table A-1 and A-2. Although it is clear that enormous savings are potentially available, they depend on achieving very low mining cost. Note that in Alaska surface mining currently occurs at a price probably above 1500 mills/MMBTU. Thus to achieve meaningful savings, underground mining in the Brooks Range will have to become half as expensive as surface mining in Alaska because of the substantial transportation costs involved in getting the Brooks Range coals to a port. In other words, underground mining in the Brooks Range would have to become about as expensive as surface mining in other parts of the world.

It is clear that there are greater savings to be obtained in the high demand case. However, note that in the high demand case, savings start occurring at a price only 50 mills/MMBTU higher than the low demand case. The very low MASP at which savings begin, together with a low sensitivity to the range of future demand, implies that the Brooks Range coals are unlikely to penetrate the Pacific Rim market in the time horizon of interest. For this reason the Alaskan coals were removed from further consideration.

B. LIGNITES

The lignites are found primarily in two large basins. The most commonly known lignite deposits lie in Montana and North Dakota. The other basin, recently analyzed by Ferm and Muthig (1982), is found along the Gulf Coast. These deposits are enormous and hold much promise. The main problem with lignites is that they are not easily transported because they are prone to spontaneous combustion. Thus for the time being, the demands for these coals are limited to consumption near the mine-mouth.

The Gulf Coast lignites are interesting because they are a resource which is located in an area where high rates of growth are expected, and hence, large energy demands are likely to occur. Another problem with these coals is their high sulfur content which makes them unable to compete for markets where sulfur content is a consideration. Underground lignites also face competition from strippable lignites, and bituminous coals will require relatively inexpensive mining systems. The savings for the lignites are shown in Tables A-3 and A-4. These numbers suggest that the underground portion of the lignites do not hold a large economic potential. In the high demand scenario, the savings are larger but still do not rival the conventional coals.

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Table A-1. Brooks Range Coals: Savings under the High Demand Scenario (Millions of 1980 Dollars/Year)

MASP Mills/MMBTU	Korea	Japan	Taiwan	U.S.	Total
700	0.07	0	0	0	0.07
650	86	15	0	0	101
600	229	86	0	0	315
550	371	175	0	0	546
500	514	276	20	115	925
450	657	384	113	295	1449
400	800	506	231	517	2054
350	942	651	350	740	2683
300	1085	802	469	962	3318

Table A-2. Brooks Range Coals: Savings under the Low Demand Scenario (Millions of 1980 Dollars/Year)

MASP Mills/MMBTU	Korea	Japan	Taiwan	U.S.	Total
650	2	0	0	0	2
600	71	6	0	0	77
550	160	31	0	0	191
500	249	67	0	115	431
450	338	130	24	295	787
400	426	206	99	517	1248
350	515	305	111	740	1671
300	604	410	124	962	2100

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Table A-3. Underground Lignites: Savings under High and Low Demand Scenarios
(Millions of 1979 Dollars/Year)

MASP Mills/MMBTU	High Demand Scenario			Low Demand Scenario		
	Low Sulfur	High Sulfur	Total	Low Sulfur	High Sulfur	Total
1500	3	0	3	0	0	0
1450	8	0	8	0	0	0
1400	12	0	12	0	0	0
1350	18	0	18	0	0	0
1300	23	42	65	0	0	0
1250	32	115	147	0	0	0
1200	44	188	232	0	0	0
1150	55	261	316	0	0	0
1100	67	334	401	0	0	0
1050	79	406	485	0	0	0
1000	90	479	569	0	0	0
950	102	552	654	0	0	0
900	114	625	739	0	0	0
850	125	698	823	0	0.2	0.2
800	137	842	979	0	70	70
750	148	1040	1188	0	186	186
700	160	1239	1399	0	304	304

Table A-4. Underground Lignites: Energy Replacement
under Low and High Demand Scenarios
(Quads/Year)

MASP Mills/MMBTU	High Demand Scenario			Low Demand Scenario		
	Low Sulfur	High Sulfur	Total	Low Sulfur	High Sulfur	Total
1500	0.093	0	0.093	0	0	0
1450	0.093	0	0.093	0	0	0
1400	0.093	0	0.093	0	0	0
1350	0.107	0	0.107	0	0	0
1300	0.107	1.456	1.563	0	0	0
1250	0.233	1.456	1.689	0	0	0
1200	0.233	1.456	1.689	0	0	0
1150	0.233	1.456	1.689	0	0	0
1100	0.233	1.456	1.689	0	0	0
1050	0.233	1.456	1.689	0	0	0
1000	0.233	1.456	1.689	0	0	0
950	0.233	1.456	1.689	0	0	0
900	0.233	1.456	1.689	0	0	0
850	0.233	1.492	1.725	0	0.036	0.036
800	0.233	3.951	4.184	0	2.330	2.330
750	0.233	3.951	4.184	0	2.330	2.330
700	0.233	3.951	4.184	0	2.355	2.355

APPENDIX B

SAVINGS COMPUTATIONS FOR THE LOW AND HIGH DEMAND SCENARIOS

Table B-1. Conventional Seams: Savings under the Low Demand Scenario (Millions of 1979 Dollars/Year)

If MASP Falls By Mills/MMBTU	Coal Types			
	Thin Drift	Thin Shaft	Medium Thick Drift	Medium Thick Shaft
50	135	1	133	80
100	257	2	276	163
150	453	3	430	272
200	608	4	605	511
250	776	5	805	662
300	946	7	1030	838
350	1119	21	1270	1056
400	1292	35	1600	1287

Table B-2. Conventional Seams: Energy Replacement under the Low Demand Scenario (Quads/Year)

If MASP Falls By Mills/MMBTU	Coal Types			
	Thin Drift	Thin Shaft	Medium Thick Drift	Medium Thick Shaft
50	2.252	0.016	2.847	1.608
100	2.440	0.020	2.920	2.010
150	3.003	0.020	3.169	2.435
200	3.100	0.024	3.357	2.911
250	3.374	0.024	4.284	3.030
300	3.400	0.285	4.792	3.415
350	3.458	0.285	4.799	3.790
400	3.498	0.285	6.818	4.692

Table B-3. Thick Coals: Savings and Energy Replacement under the Low Demand Scenario

MASP Mills/MMBTU	SAVINGS (Millions 1979 $/Year)	ENERGY REPLACEMENT (Quads/Year)
1450	0	0
1400	0	0
1350	0	0
1300	0	0
1250	0	0
1200	0	0
1150	0	0
1100	0	0
1050	0	0
1000	89	2.774
950	254	4.478
900	478	4.478
850	702	4.513
800	995	6.807

Table B-4. Thin Dritt Coals: Savings under the Low Demand Scenario
(Millions of 1979 Dollars/Year)

It MASP Falls Mills/MMBTU	Sulfur			TOTAL SAVINGS
	Compliance	Low	High	
50	37	55	44	136
100	74	109	74	257
150	110	166	177	453
200	146	225	237	608
250	183	287	306	776
300	220	349	377	946
350	256	411	452	1119
400	293	473	527	1293

Table B-5. Thin Drift Coals: Energy Replacement
under the Low Demand Scenario
(Quads/Year)

If MASP Falls Mills/MMBTU	Sulfur			TOTAL QUANTITY
	Compliance	Low	High	
50	0.732	1.052	0.468	2.252
100	0.732	1.139	0.569	2.440
150	0.732	1.157	1.114	3.003
200	0.732	1.165	1.203	3.100
250	0.732	1.229	1.412	3.373
300	0.732	1.238	1.430	3.400
350	0.732	1.238	1.488	3.458
400	0.732	1.246	1.520	3.498

Table B-6. Thin Shaft Coals: Savings under the Low Demand Scenario (Millions of 1979 Dollars/Year)

If MASP Falls Mills/MMBTU	Sulfur			TOTAL SAVINGS
	Compliance	Low	High	
50	0	1	0	1
100	0	2	0	2
150	0	3	0	3
200	0	4	0	4
250	0	5	0	5
300	0	6	1	7
350	0	7	14	21
400	0	9	27	36

Table B-7. Thin Shaft Coals: Energy Replacement under the Low Demand Scenario (Quads/Year)

If MASP Falls Mills/MMBTU	Sulfur			TOTAL QUANTITY
	Compliance	Low	High	
50	0	0.016	0	0.016
100	0	0.020	0	0.020
150	0	0.020	0	0.020
200	0	0.024	0	0.024
250	0	0.024	0	0.024
300	0	0.024	0.261	0.285
350	0	0.024	0.261	0.285
400	0	0.024	0.261	0.285

Table B-8. Medium Thick Drift Coals:
Savings under the Low Demand Scenario
(Millions of 1979 Dollars/Year)

If MASP Falls Mills/MMBTU	Sulfur			TOTAL SAVINGS
	Compliance	Low	High	
50	24	63	45	132
100	49	132	95	276
150	75	204	151	430
200	101	287	217	605
250	141	370	294	805
300	190	464	376	1030
350	239	571	461	1271
400	297	751	552	1600

Table B-9. Medium Thick Drift Coals: Energy Replacement
under the Low Demand Scenario
(Quads/Year)

If MASP Falls Mills/MMBTU	Sulfur			TOTAL QUANTITY
	Compliance	Low	High	
50	0.488	1.373	0.986	2.847
100	0.488	1.377	1.055	2.920
150	0.529	1.456	1.184	3.169
200	0.529	1.525	1.303	3.357
250	0.976	1.729	1.579	4.284
300	0.976	2.130	1.686	4.792
350	0.976	2.130	1.692	4.798
400	1.493	3.529	1.797	6.819

Table B-10. Medium Thick Shaft Coals:
Savings under the Low Demand Scenario
(Millions of 1979 Dollars/Year)

If MASP Falls Mills/MMBTU	Sulfur			TOTAL SAVINGS
	Compliance	Low	High	
50	0	75	5	80
100	0	153	10	163
150	0	253	19	272
200	0	471	40	511
250	0	598	64	662
300	0	733	105	838
350	0	861	195	1056
400	0	1026	262	1288

Table B-11. Medium Thick Shaft Coals:
Energy Replacement under the Low Demand Scenario
(Quads/Year)

If MASP Falls Mills/MMBTU	Sulfur			TOTAL QUANTITY
	Compliance	Low	High	
50	0	1.510	0.098	1.608
100	0	1.875	0.135	2.010
150	0	2.015	0.420	2.435
200	0	2.492	0.420	2.912
250	0	2.523	0.507	3.030
300	0	2.574	0.841	3.415
350	0	2.578	1.212	3.790
400	0	3.322	1.370	4.692

Table B-12. Thick Coal: Savings under the Low Demand Scenario (Millions of 1979 Dollars/Year)

If MASP Falls Mills/MMBTU	Sulfur			TOTAL SAVINGS
	Compliance	Low	High	
1000	45	44	0	89
950	115	39	0	254
900	184	294	0	478
850	254	448	0.2	702
800	323	602	70	995

Table B-13. Thick Coal: Energy Replacement under the Low Demand Scenario (Quads/Year)

If MASP Falls Mills/MMBTU	Sulfur			TOTAL QUANTITY
	Compliance	Low	High	
1000	1.389	1.384	0	2.773
950	1.389	3.088	0	4.477
900	1.389	3.088	0	4.477
850	1.389	3.088	0.036	4.513
800	1.389	3.088	2.330	6.807

Table B-14. Alteration of Coal Flow Due to New Technology under the Low Demand Scenario (MASP at Which Flows Change in Mills/MMBTU)

COAL TYPE	THIN DRIFT			THIN SHAFT			MEDIUM DRIFT			MEDIUM SHAFT		
SULFUR TYPE	Supply Region	To Demand Region	To Replace Supply Region	Supply Region	To Demand Region	To Replace Supply Region	Supply Region	To Demand Region	To Replace Supply Region	Supply Region	To Demand Region	To Replace Supply Region
Compliance	NONE	NONE	NONE	NONE	NONE	NONE	13(813) 3(1072)	11 7	11 4	NONE	NONE	NONE
Low	5(1113) 5(1151) 5(1143)	4 9 4	1 4 3	2(1438)	1	3	5(1143) 5(1159) 5(1113)	4 9 1	3 4 4	5(1113) 5(1143) 5(1151) 5(957) 5(934)	4 4 9 6 6	1 3 4 3 4
High	2(951) 2(986) 2(965) 5(851) 5(787) 5(531)	5 6 6 7 7 10	3 3 4 4 7 6	1(832) 5(923)	3 6	2 3	3(1138) 5(851) 5(787)	6 7 7	4 4 7	2(951) 2(986) 2(965) 5(851)	5 6 6 7	3 3 4 4

Table B-15. Conventional Seams: Savings under the High Demand Scenario (Millions of 1979 Dollars/Year)

If MASP Falls By Mills/MMBTU	Coal Types			
	Thin Drift	Thin Shaft	Medium Thick Drift	Medium Thick Shaft
50	626	41	670	409
100	913	81	1166	617
150	1272	129	1678	1008
200	1656	181	2192	1423
250	2051	242	2688	1867
300	2409	309	3371	2298
350	2874	381	3980	2757
400	3337	515	4837	3233

Table B-16. Conventional Seams: Energy Replacement under the High Demand Scenario (Quads/Year)

If MASP Falls By Mills/MMBTU	Coal Types			
	Thin Drift	Thin Shaft	Medium Thick Drift	Medium Thick Shaft
50	5.557	0.812	9.885	4.257
100	5.702	0.820	9.949	4.292
150	6.246	0.940	10.122	6.936
200	7.871	0.940	10.164	7.692
250	7.910	1.212	10.223	8.341
300	8.270	1.366	11.592	8.533
350	8.691	1.628	13.032	8.991
400	9.150	2.576	15.970	9.264

Table B-17. Thick Coals: Savings and Energy Replacement under the High Demand Scenario

MASP Mills/MMBTU	SAVINGS (Millions 1979 $/Year)	ENERGY REPLACEMENT (Quads/Year)
1800	0	0
1750	0	0
1650	0	0
1600	0	0
1550	0	0
1500	0	0
1450	0	0
1400	0	0
1350	0	0
1300	41	1.456
1250	114	1.456
1200	186	1.456
1150	259	1.456
1100	411	3.238
1050	606	4.831
1000	971	8.642
950	1429	8.642
900	1946	10.346
850	2464	10.382
800	3044	12.676

Table B-18. Thin Drift Coals: Savings under the High Demand Scenario (Millions of 1979 Dollars/Year)

If MASP Falls Mills/MMBTU	Sulfur			TOTAL SAVINGS
	Compliance	Low	High	
50	37	278	312	627
100	73	416	424	913
150	110	555	608	1273
200	146	695	814	1655
250	183	839	1029	2051
300	220	942	1248	2410
350	256	1125	1492	2873
400	293	1269	1775	3337

Table B-19. Thin Drift Coals: Energy Replacement under the High Demand Scenario (Quads/Year)

If MASP Falls Mills/MMBTU	Sulfur			TOTAL QUANTITY
	Compliance	Low	High	
50	0.732	2.770	2.055	5.557
100	0.732	2.770	2.200	5.702
150	0.732	2.770	2.745	6.247
200	0.732	2.862	4.276	7.870
250	0.732	2.862	4.316	7.910
300	0.732	2.862	4.675	8.269
350	0.732	2.876	5.082	8.690
400	0.732	2.876	5.541	9.149

Table B-20. Thin Shaft Coals: Savings under the High Demand Scenario (Millions of 1979 Dollars/Year)

If MASP Falls Mills/MMBTU	Sulfur			TOTAL SAVINGS
	Compliance	Low	High	
50	0.2	40	0	40
100	0.4	81	0	81
150	2	126	0	128
200	5	171	5	181
250	9	215	18	242
300	15	263	31	309
350	23	311	48	382
400	67	374	74	515

Table B-21. Thin Shaft Coals: Energy Replacement under the High Demand Scenario (Quads/Year)

If MASP Falls Mills/MMBTU	Sulfur			TOTAL QUANTITY
	Compliance	Low	High	
50	0.004	0.808	0	0.812
100	0.004	0.816	0	0.820
150	0.059	0.881	0	0.940
200	0.059	0.881	0.261	1.201
250	0.066	0.885	0.261	1.212
300	0.154	0.951	0.261	1.366
350	0.154	0.951	0.522	1.627
400	0.647	1.407	0.522	2.576

Table B-22. Medium Thick Drift Coals: Savings under the High Demand Scenario (Millions of 1979 Dollars/Year)

If MASP Falls Mills/MMBTU	Sulfur			TOTAL SAVINGS
	Compliance	Low	High	
50	73	182	414	669
100	146	320	700	1166
150	220	456	1002	1678
200	293	593	1306	2192
250	367	717	1604	2688
300	571	866	1934	3371
350	722	1003	2255	3980
400	934	1332	2570	4836

Table B-23. Medium Thick Drift Coals: Energy Replacement under the High Demand Scenario (Quads/Year)

If MASP Falls Mills/MMBTU	Sulfur			TOTAL QUANTITY
	Compliance	Low	High	
50	1.464	2.733	5.659	9.856
100	1.468	2.733	5.749	9.950
150	1.468	2.733	5.921	10.122
200	1.468	2.733	5.963	10.164
250	1.474	2.733	6.016	10.223
300	2.647	2.773	6.212	11.592
350	3.106	3.629	6.296	13.031
400	3.760	5.886	6.323	15.969

Table B-24. Medium Thick Shaft Coals: Savings under the High Demand Scenario (Millions of 1979 Dollars/Year)

If MASP Falls Mills/MMBTU	Sulfur			TOTAL SAVINGS
	Compliance	Low	High	
50	0	377	32	409
100	0	574	43	617
150	0	786	221	1007
200	0	1000	423	1423
250	0	1215	651	1866
300	0	1431	866	2297
350	0	1647	1111	2758
400	0	1866	1367	3233

Table B-25. Medium Thick Shaft Coals: Energy Replacement under the High Demand Scenario (Quads/Year)

If MASP Falls Mills/MMBTU	Sulfur			TOTAL QUANTITY
	Compliance	Low	High	
50	0	3.872	0.385	4.257
100	0	3.907	0.385	4.292
150	0	4.205	2.731	6.936
200	0	4.307	3.384	7.691
250	0	4.307	4.033	8.340
300	0	4.314	4.218	8.532
350	0	4.314	4.677	8.991
400	0	4.384	4.880	9.264

Table B-26. Thick Coal: Savings under the High Demand Scenario
(Millions of 1979 Dollars/Year)

If MASP Falls Mills/MMBTU	Sulfur			TOTAL SAVINGS
	Compliance	Low	High	
1300	0	0	41	41
1250	0	0	114	114
1200	0	0	186	186
1150	0	0	259	259
1100	79	0	332	411
1050	183	19	405	607
1000	360	134	478	972
950	566	312	551	1429
900	772	551	623	1946
850	979	789	696	2464
800	1185	1027	832	3044

Table B-27. Thick Coal: Energy Replacement
under the High Demand Scenario
(Quads/Year)

If MASP Falls Mills/MMBTU	Sulfur			TOTAL QUANTITY
	Compliance	Low	High	
1300	0	0	1.456	1.456
1250	0	0	1.456	1.456
1200	0	0	1.456	1.456
1150	0	0	1.456	1.456
1100	1.781	0	1.456	3.237
1050	2.478	0.897	1.456	4.831
1000	4.124	3.061	1.456	8.641
950	4.124	3.061	1.456	8.641
900	4.124	4.765	1.456	10.345
850	4.124	4.765	1.492	10.381
800	4.124	4.765	3.786	12.675

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Table B-28. Alteration of Coal Flow Due to New Technology under the High Demand Scenario
(MASP at Which Flows Change in Mills/MMBTU)

COAL TYPE	THIN DRIFT			THIN SHAFT			MEDIUM DRIFT			MEDIUM SHAFT		
SULFUR TYPE	Supply Region	To Demand Region	To Replace Supply Region	Supply Region	To Demand Region	To Replace Supply Region	Supply Region	To Demand Region	To Replace Supply Region	Supply Region	To Demand Region	To Replace Supply Region
Compliance	13(1326)	7	3	4(2099)	7	3	13(1326)	7	3	NONE	NONE	NONE
				14(1033)	14	15	13(717)	12	11			
							13(1033)	14	15			
Low	5(1768)	4	3	1(1314)	1	2	5(1768)	4	3	5(1768)	4	3
	5(1583)	6	3	3(1406)	2	2	7(1455)	4	1	5(1583)	6	3
	5(1411)	5	3				13(1052)	11	7	5(1411)	5	3
High	1(829)	7	4	1(934)	3	2	2(986)	5	3	1(803)	1	2
	1(655)	7	7	5(1043)	12	6	2(1021)	6	3	1(799)	2	2
	2(986)	5	3				2(1131)	6	4	1(934)	3	2
	2(1021)	6	3				5(1043)	12	6	3(1235)	5	2
	2(965)	6	4				5(717)	7	4	5(934)	6	4
	5(1043)	12	6				5(787)	7	7	5(964)	6	2
	5(989)	12	5				5(987)	12	5	5(717)	7	4
							5(592)	10	6	5(787)	7	7
							7(1001)	11	6	5(592)	10	6
										5(1043)	12	6
										5(685)	8	8
										5(958)	6	3

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